Aircraft Design – C

Assignment [52, Assignment 1]: Mission definition, Analysis of Requirements, Concept Selection and Fuselage Design]

Student Names and Study Numbers:
[,]
[, 13]

Instance [first delivery]
Hours spent on assignment: [35]

Aircraft type: Passenger Transport Airliner
Aircraft number: 52

Requirement type	Value	Unit
Payload	190	passengers
Range	5500	km
Cruise altitude	11800	m
Cruise speed	0.82	Mach
Take-off distance	2100	m
Landing distance (at maximum weight)	1650	m

Table 1.1: Matrix Requirements

Table of Contents

1. Introduction

This report consists of five main chapters. The first chapter (chapter 2) will give a short description of the mission definition and will analyze the given requirements. Next, chapter 3 will show the similarities between different aircraft in the given aircraft's range, by making use of an appendix showing all reference aircraft used in this report. After that, chapter 4 deals with the generation of 3 concepts and the selection of the optimal concept for the given requirements. Chapter 5 will show the complete fuselage layout of the chosen concept. Finally, in chapter 6, some technical drawings will be shown, indicating the most important measurements of the concept aircraft.

2. Mission Definition and analysis of requirements

In the introduction, the requirements were given for a commercial transport aircraft. This is however not the complete list of requirements. There are more requirements coming from FAA regulations or and some elements have to be there just for passenger comfort. In this chapter an attempt will be made to sum up the complete list of requirements that are necessary to start designing a commercial aircraft.

2.1 The mission

The main characteristics of an airliner are, just to name a few: the size of the wing, empty weight, the number of engines… Their main goal is to transport passengers and cargo from place A to place B. This may also involve transatlantic flights which may influence some aspects of the airliner as the choice of the engine as it will be seen later on. A typical mission as flown by hundreds of aircraft each day is shown in figure 2.1.

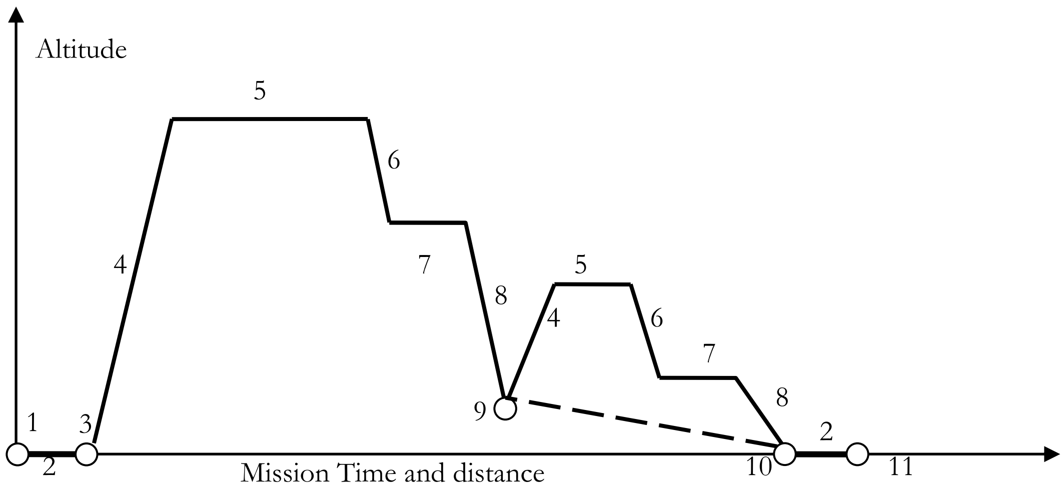


Figure 2.1: Steps of a typical mission for a short-range commercial airliner

Step Description

1 <u>Engine startup.</u> Shortly after boarding is complete, the doors are closed and the aircraft is ready to go. After being pushed back (if necessary), the pilot gets permission to start the engines. This is where every flight starts. This is also the point at which the block-time starts counting. After the engines are started, the plane's energy source is transferred from APU (auxiliary power unit) to engine generators. All systems are checked one more time, to make sure the aircraft is performing nominal before taxiing.

2 <u>Taxi.</u> The aircraft gets permission to move. It is now moving from the parking point or gate to the runway where it will take off or vice versa. It does so via the designated taxiways, which are constructed strong enough, so that the aircraft does not sink in the ground. During taxi, the brakes are used extensively, in combination with the engines that provide thrust.

3 <u>Take off.</u> The pilot is lined up on the runway and slowly raises the throttle from idle to full power. The engines now have the hardest time of the whole flight: they have to perform and provide thrust at a power setting slightly higher than maximum, so the airplane sometimes literally gives 110% to get off the ground. Statistics have shown that take-off is the most crucial part of the whole flight. Take-off usually refers to the status of the aircraft from standing still till reaching the screen height of 50ft.

4 <u>Climb.</u> The aircraft slowly reduces power but maintains a high power to perform the climb to cruise. The aircraft's heading is also changed in this part, requiring some more power. As the aircraft reaches cruise level, it levels off and reduces power even further, so that the engines perform the cruise at the right speed. (That speed is determined by fuel economy or by time to destination).

5 <u>Cruise.</u> The aircraft stays at about the same altitude for the larger portion of the flight. Depending on the type of aircraft, cruise can range from 5 minutes till 15 hours. The cruise phase is the phase in which the aircraft simply travels from point a to b.

6 <u>Descend.</u> At the end of the cruise, the descent phase is initiated: the aircraft starts to slow down and lowers its altitude, so it can make preparations to land.

7 <u>Loiter.</u> Sometimes, during descent, the aircraft has to enter a pattern, or circle to wait for an available landing slot. This part is called the loiter part of the flight. The durations of the loiter depends on the waiting time to land.

8 <u>Approach.</u> The aircraft starts to deploy flaps, and reduces speed to a safe landing speed. The weight, speed and weather are checked, so that the pilots are fully aware of the conditions on the ground and that the gear can take the impact of landing without failure. The gear is deployed in the final stage, just before touchdown.

9 <u>Missed approach.</u> If for some reason (this can be visibility, winds or weather in general, but also pilot error, airport traffic or any other reason why the control tower forbids the pilot to land) the pilot had a missed approach, he has to climb again to a safe altitude and start the whole approach again from step 4. If the pilot does succeed in landing the plane directly, then the flight continues from step 10.

10 <u>Touchdown/landing.</u> When the aircraft touches the ground, the main gear touches down first, then the nose gear. The aircraft starts (if it has the possibility) reversing the engines to create more resistance, and deploys the spoilers, which destroy the smooth airflow over the wing, resulting in a dramatic loss of lift, which in turn keeps the aircraft on the ground. If it is sufficiently slowed down, the pilot stops the reversing, and continues the braking with the gear's brakes. This makes the aircraft stop, or at least come to taxi-speed.

11 <u>Shut down.</u> The aircraft is now parked at the ramp, gate or parking and has completed its flight. This is the end-point of the block time. The mission is over and all payload is being unloaded. Passengers disembark and cargo is hauled from the cargo compartment. The engines are shut down and APU or External power is switched on or plugged in, so the aircraft's systems can still be used even when the engines are off.

2.2 Requirement Analysis

In this chapter, a small analysis of the requirements will be made, so that any missing requirements are found and calculated. This is important to start the design process in chapter 3. Of course the obvious requirements are that the aircraft is able to travel a certain range without refuelling, or crashing. The standard operating mission profile will look (like in figure 1) where sometimes redirection to a different airport may occur and this should also be taken into account in the fuel-budget of the aircraft. This also means that the aircraft should be able to perform some extreme manoeuvres, like fight heavy turbulence or winds or even get through heavy precipitation unharmed. The aircraft should also be redundant in a way such that for example if one engine fails, not all is lost, and the aircraft can divert to the nearest airfield and still land and operate normally under the circumstances

2.2.1 Payload analysis

It is given that the aircraft should accommodate 190 passengers. Standard procedures require a presence of 2 pilots and for passenger comfort per 50 passengers a flight attendant, in full economy. The total number of available seats should therefore be 196, including a crew of 2 pilots and 4 attendants to the initial 190 passenger requirements. From the requirements, the amount of cargo that has to be transported is missing. In the next part this will briefly be calculated.

Each passenger will require the transfer of himself and his cargo, in the form of his overhead carryon luggage or his baggage. For airliners, it is common to allow each passenger to bring 20kg of baggage in a standard-sized suitcase along with a 5kg carry-on bag. This suitcase is usually about 80cm by 40cm by 60cm. Or the volume of baggage per passenger is 0.8*0.4*0.6= 0.192m^3.

When multiplying this by the amount of passengers, we get that a plane of 196 passengers needs to have 196*0.192 = 37.63m^3 of cargo volume and the cargo weight is 20kg*196 = 3920kg. Now those 196 passengers will bring aboard an average of 196*5=980kg worth of carryon items. And assuming a general bodyweight of each passenger of 80kg, the total weight of all passengers is 196*80 = 15680kg. The sum of all payload mass is calculated in table 2.1.

Cargo	3920kg
Carry-on	980kg
Crew+Pax	15680kg
TOTAL Payload + crew	20580kg

Table 2.1: Total payload mass.

Now; continuing with the fact that the aircraft should have at least the given amount of payload, it is always good to have some margins on those values. Therefore: from now on, the total passengers, crew and cargo weight will be referred to as 22000kg, and the total cargo volume is at least 40m^3.

Keeping in mind that the payload type is passengers, it immediately becomes clear that at a given cruise altitude of 11800m, the cabin must be a pressurized, where the pressure inside the vehicle will be as high as 10 times the pressure outside, so that the passengers can at all times be in an acceptable climate. This requirement includes the need for a stronger fuselage than with non-pressurized aircraft.

The aircraft should also have a flexible design, allowing several configurations of passengers in 2 or even 3 different classes, according to the airline's desires. Yet the most important part here is that the passengers have a good clearance to the surroundings, being the ceiling, aisles seat pitch and seat widths. These measurements should be large enough to ensure a clean evacuation in the event of an emergency.

And finally, a part of the aircraft that is not really considered payload but very important to the success of the aircraft: the fuel. In order to be able to fulfill the depicted mission in 2.1, there should be enough fuel to do so. This fuel also ads big numbers to the total weight of the aircraft. Because the fuel is mostly stored inside the wings, the total fuel weight will strongly amount to the design of the wings.

2.2.2 Propulsion analysis

When given a speed of mach 0.82 in the transonic range, only 2 types of aviation propulsion come to mind: a typical turbofan can be used, or a new type of open duct turbofan can also be used. This speed is too high for an efficient propeller aircraft, and too low for ramjet or scramjet engines. So the choice is not so extensive on this aspect. An image of both types of turbofans can be seen in figures 2.2 and 2.3.

Figure 2.2: Standard turbofan

Figure 2.3: Unducted turbofan

Because the technology of unducted fans is still in its early stages, in this assignment, a set of 2 simple ducted turbofans will be used to propel the aircraft.

2.2.3 Certification analysis

According to JAR regulations, this aircraft automatically belongs to the set of requirements described in JAR 25, belonging to the group of large commercial airplanes. These requirements also contain regulations related to noise, pollution, safety, visibility angles… Many of these extra requirements are only needed when the design has begun, since different sets of rules apply to different configurations. In chapter 4, when a concept is chosen, those requirements will be explained and taken into account.

2.2.4 Range, take-off and landing distance

For the given value of range, being 5500km, it becomes clear that this will be a short-haul medium-sized aircraft optimized for quick turnaround times, and efficient fuel-usage.

The take-off distance is the distance from the moment the brakes are released till the moment that the aircraft reaches a safe screen height. A take-off length of 2100m allows landing at most regional airports, and of course also all national or international airports. During the performance-driven part of the design, the take-off distance becomes a significant part in the engine and wing design. The take-off length is shown in figure 2.4.

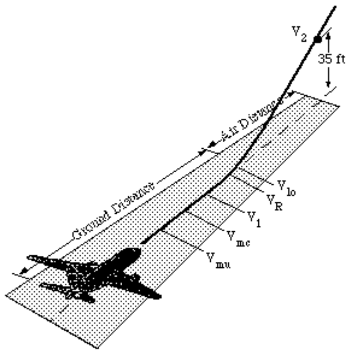


Figure 2.4: Take-off length of an airliner

The landing distance required for this aircraft is 1650 m. It is desired to land with the lowest speed possible for the smallest landing distance possible. The problem of having high and low loading on the wings in different segments are the driving ideas for the configuration of the wing just like it was mentioned with the take off distance. Also the density of air must be considered, since different airports have different climates which could, besides the high lift devices, affect the landing speed of the aircraft. However, these requirements are part of the performance of the aircraft, which is determined in a later stage of development.

The most important design criteria with this aircraft, as it is for many other airliners too, will be getting the payload from A to B safely, on time, according to the rules and efficiently.

2.2.5 Additional requirements

Apart from the requirements given above; there are some more requirements, mostly to do with human interaction. Examples are the number of restrooms, the galley volume; the number of flight attendants… these requirements can be deduced from comparison to other airliners in the reference, or by looking at the aircraft design lecture notes. The reference aircraft can be found in Appendix B. Some additional requirements are determined in table 1.4

Requirement type	Value		Our Aircraft
No. of passengers	190		
Pressurized	Yes		
Overnose angle	>11 deg		*To Be Determined*
Overside angle	> 35 deg		*TBD*
Grazing angle	> 30 deg		*TBD*
Lavatories/passenger	1/ (40 -50)		
Total lavatories			4 toilets
Galley volume/passenger	1 ft³	0.0283 m³	1m wide, cabin height high. (about 8m³)
Total galley volume		5.38 m³	6 m³
Baggage/passenger	40 lbs	18.18 kg	20 kg
Total baggage (passengers + 6 crew)	7840 lbs	3563 kg	3920

Table 2.2. Additional requirements.

2.3 Driving requirements

While looking for comparable aircraft in the reference aircraft section, priority will be given to the aircraft that have the same payload (amount of passengers), range and speed.

3. Reference aircraft data collection

In order to find a good concept, a set of reference aircraft is built to compare with the new design. All the reference aircrafts are given in Appendix B. There is a wide scope of aircraft given to find which ones will be the most similar to the design aircraft. Yet there are also some aircrafts with data's at extremities in order to have a reference as to how small and larger aircrafts operate and thus could be used to create a curved reference.
Furthermore, attention was paid to the critical requirements, payload and ranges during collecting this data. All other requirements for the aircraft to be designed are also written in the first row as an easy method of comparison. The two most similar aircrafts are the A320-200 and the B 737-800. **T**hose two and a few other similar aircraft are listed in table 3.1 below. It is important however to realize that this table will be an active table, along with the aircraft specifications, and that this table will be updated with every assignment.

Manufacturer	Type	Payload	Range at MTOW	range	Cruise altitude	Service ceiling	Cruise speed	Take off distance	Landing distance At MLW
		Pax	[km]	[km]	[m]	[m]	[Mach]	[m]	[m]
Our Aircraft		190		5500	11800		0,82	2100	1650
airbus	A320-200	180		5600	12000	12000	0,82	2180	
Airbus	A321-200	220		5600	12000		0,82	2180	
Boeing	737-800	189		5670	12500		0,785	2525	
Boeing	707-320B	202	10650	6920			972 km/h	3280	1813
Boeing	727-200	189		4450			0,81	1768	1585
Ilyushin	Il-62	168-186		9,2		12000			
Shanghai	Y-10	178		8300		12000			
Tupolev	Tu-114 Rossiya	120-220		6200		12000	770 km/h		
Tupolev	Tu-154	114-180	2500			12100			
McDonnell Douglas	MD-81	172	2910				.76		

Table 3.1: Sample from the reference aircraft table, as can be found in appendix B

4. Concept generation and selection

4.1 Concept generation

In this section, different considered concepts will be described and analyzed and the pros and cons of each concept will be given. Thought was given to design a future concept, so a non-conventional aircraft configuration is considered. This because of it's the originality but also because of the typical challenging requirements for the civil air transport of the future. The considered concepts are:

- The Blended Wing Body configuration (BWB)

    - Wing configuration: low, blended
    - Engines configuration: blended in top of wing
    - Tail plane configuration: none

- The first conventional configuration

    - Wing configuration: low
    - Engines configuration: tail mounted
    - Tail plane configuration: conventional T-tail

- The second conventional configuration

    - Wing configuration: low
    - Engines configuration: under-wing mounted
    - Tail plane configuration: conventional tail

For all concepts, the same seat-layout will be used. This layout includes room for 4 attendants, 190 passengers and 2 pilots. The seats are mounted in a 3-3 configuration, which is optimal for these designs. Emergency exits are not included in these drawings, since that is reserved for when the final concept is chosen at the end of this chapter. Figure 4.1 shows the seat-layout of the cabin of each concept.

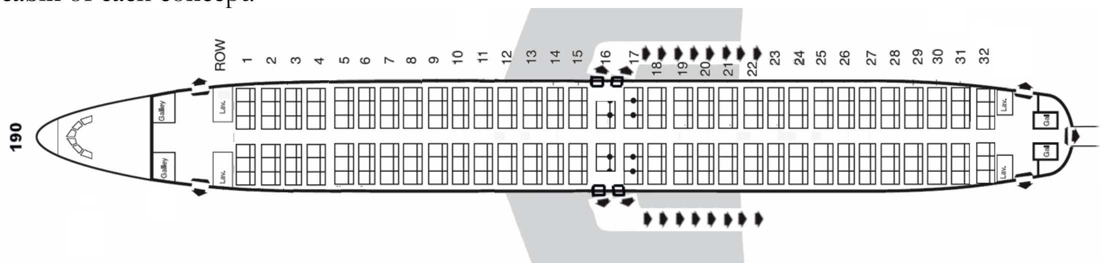


Figure 4.1: the 1-class cabin configuration of each concept.

In the design of our aircraft, only low-wings were chosen. Even though mid-wing configurations have less drag, they are harder to install and design and not common for commercial aviation. High mounted wings are not chosen since they would not be advantageous in this configuration: the landing gear would have to be too large, and the cabin would be intersected with a big piece of the center-wing box. This is why only low mounted wings are chosen: the wings can intersect the fuselage without worrying about cabin intersection, landing gears and difficult design parameters.

In the next subchapters, each concept will be explained briefly.

4.1.1 The Blended Wing Body configuration

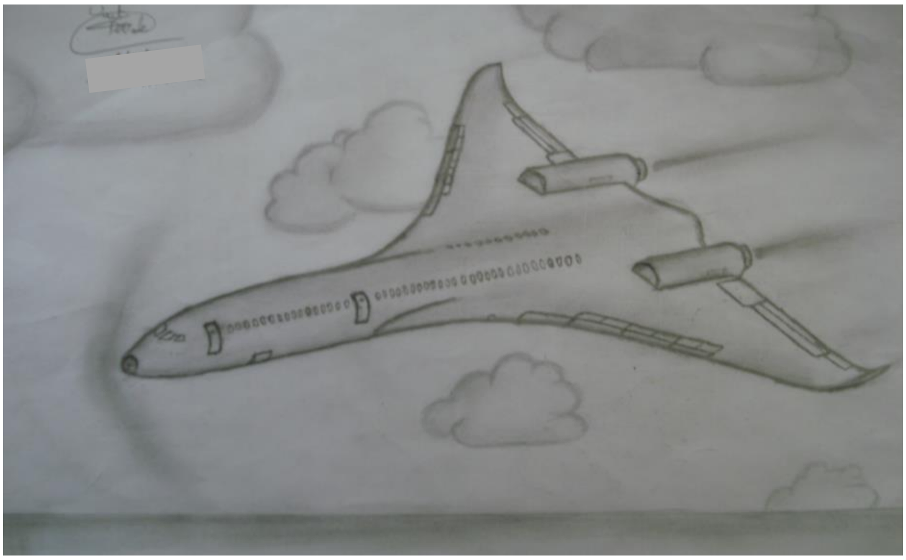


Figure 4.2: The first concept; a blended winged body sketch.

This is a future concept for a blended wing body. It satisfies the passenger requirement of 190 pax, and could also comply with the performance requirements for range, cruise altitude, speed and takeoff and landing-distances (see table 1.1). Although for that, a more detailed analysis would be required. The choice of a blended wing body is made because the concept is interesting, since it is at the frontlines of common days development and it is undoubtedly the future for commercial aviation. It is supposed to have low parasite drag, since the fuselage also carries part of the lifting loads. Because the concept is supposed to carry only 190 passengers, it was chosen that the passengers should not sit inside the wing, and that that room was reserved for fuel, cargo and engines. This is also beneficial for the pressurization of the fuselage, since this almost maintains it circularity.

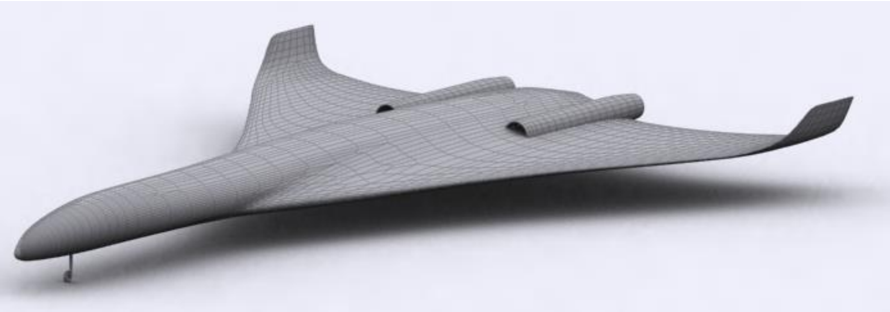
No tail was selected for this concept. It is assumed that the aircraft would be able to perform rudder actions by increasing drag or by varying thrust in the engines or maybe by use of small rudders in the winglets. The engines are semi-buried in the wing to optimize the airfoil efficiency and reduce noise on the ground.

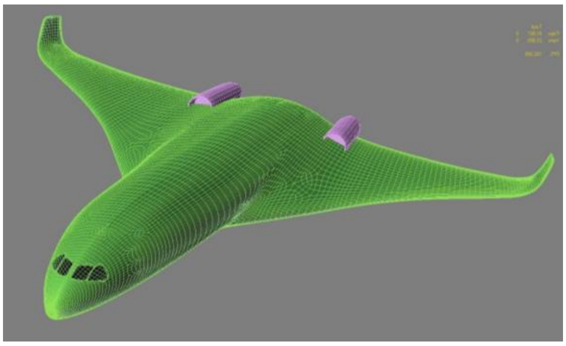
The Advantages and disadvantages for this concept were put together in table 4.1

Pros	Cons
Improved fuel consumption, since the aerodynamic shape is optimized.	The BWB does not have large moment arms for generating control moments. Especially around the vertical axis (due to lack of tail)
Improved structural weight	Low or absent possibility of side windows for passengers near the rear of the fuselage
Significant payload advantages and speed improvements.	No tail may be hard to certificate. And may cause reasons for concern if an engine failure occurs.
Wing bending relief	Engines are hard to maintain, it is also difficult to change the engine design or type.
	Dangerous engine placement concerning engine fire.

Table 4.1: Pros and cons of this blended wing body concept.

Two more sketches can be seen in figures 4.3-4.5.





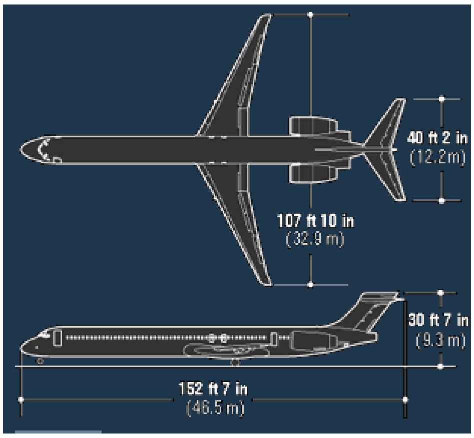
Figures 4.3-4.5: Pros and cons of this blended wing body concept.

Note: these sketches were made in 3ds max, by the authors of this report. The shape drawings do not include accurate position or angles of windows, gears, engines, wings or emergency exits. Also note that the drawings at the beginning of each concept are hand drawings on which emergency exits etc. are also not in the correct positions.

The concept sketches can be found in appendix A.1

4.1.2 The first conventional configuration

This configuration contains a T-tail; rear-mounted low wings with engines attached to the rear of the fuselage / beginning of the tail. This concept is based on the md-90 aircraft (which carries 187 pax at maximum capacity), but then a slightly larger model, suitable for 190 passengers. Figure 4.6 shows an image and schematics of the md-90. Since the wings are mounted near the rear of the fuselage, then a normal horizontal tail plane would nearly always be in a turbulent flow. That is why a T-tail will be used on this concept. The engines here are podded on the tail, which makes them more protected from the debris from the ground. It is also safer for ground personnel to walk around the aircraft when the engines are on. Since the engines are mounted on the rear, the wings have to be more to the back too, to keep the center of gravity within balance.



Figures 4.6: The McDonnell Douglas 90

The Advantages and disadvantages for this concept were put together in table 4.2

Pros	**Cons**
Easy design and relatively easy to find references from already-existing planes.	Large moments working on the fuselage due to rear-mounted wings. This results a heavier fuselage structure
Long and simple fuselage, many sections and cross sections are the same.	Very large tail needed to create sufficient moments around the vertical axis of the plane.
Thrust closer to centerline, an advantage in case of engine failure.	Vibrations on the fuselage are increased due to the fuselage-mounted engines. This can be dangerous for pressurization.
Engines stowed out of reach of handling personnel.	The tail section has to be very strong, so it can carry the engines, and the T-tail.
Good ground clearance.	Wing turbulence may affect tail plane when at high angles of attack.

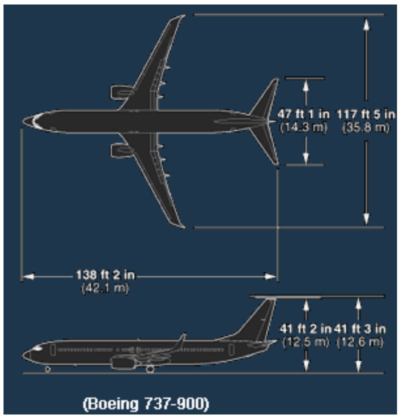
Table 4.2: Pros and cons of this conventional aircraft concept.

These concepts sketches can be found in appendix A.2.

4.1.3 The second conventional configuration

Figures 4.7: The third concept; a second version of a standard airliner sketch.

In this section the conventional configuration of an airliner will be analyzed. This type of configuration is the most used configuration available in current aviation. Reference lists are endless and they exist in all sizes. This makes performance and other characteristics easier to estimate. This concept is based on the 737-800 aircraft (which carries 189 pax at maximum capacity), but then a modified version, which fits the requirements of our airliner. Figure 4.8 shows an image and schematics of the Boeing 737-800. The engines are podded below the wing. This makes them easy replaceable and adjustable. This is also an advantage in case of engine fire.



Figures 4.8: The Boeing 737-800.

The Advantages and disadvantages for this concept are in table 4.3

Pros	Cons
Easy design and relatively easy to find references from already-existing planes. Long and simple fuselage, many sections and cross sections are the same.	Engine-ground and wing-ground clearance can be small, enough clearance must be assured (e.g. during landing in crosswinds).
Good performance in case of emergency landing on ground or on water.	The wing should be very strong, to support all possible loads from the landing gear (e.g. touchdown) and engines.
Low vibrations on the fuselage because the engines are mounted on the wings.	Caution should be made when designing the flaps, so that they don't interact in a negative way with the hot engine exhaust.
Good possibility to store the landing gear in the wings and fuselage.	Engines are close to the ground, danger for sucking in debris from the airfield.
Easy maintenance of the engines	
Wing bending relief	

Table 4.3: Pros and cons of this conventional aircraft concept.

The front, side and top-view of this concept can also be found in appendix A.

4.2 Concept selection

Despite its futuristic aspects and probably improved performance, concept 1 was eliminated because it was, among other arguments, still too difficult to be selected as the main concept design, due to the complexity of the aircraft and the limited timeframe in which the assignment had to be made. The main argument that this concept wasn't chosen, besides that there are little references available, is that usually this concept will have the advantage of carrying a large number of passengers and in this assignment the required payload is typical that of a small to medium airliner.

The second concept is not such a good concept because the engine empennage on the fuselage inhibits the storage of payload on that location. This also increases vibrations, which can become dangerous for the whole tail section. Reducing these vibrations requires strong materials, which means a heavy construction, which is bad for overall aircraft efficiency. For those reasons we did not choose for concept 2.

Eventually, the third concept was chosen: a standard commercial aircraft layout with a monocoque fuselage, two low mounted wings and two under-wing engines (one on each wing). The tail is built up from two separate components: the horizontal and vertical tail plane are not interrelated. This choice not only simplified the design process, it is also the most common aircraft configuration of all aircraft flying today.

5. Study and generation of the complete fuselage layout

In this chapter, an inside-out approach will be used to make the design of the fuselage. Using cross-sections, a final fuselage layout will be obtained.

5.1 Fuselage Front Cross-section layout

5.1.1 Passenger seats

Using standard seat dimensions, the needed width of the fuselage will be found. Standard airline seats are between 30 and 32 inch wide (using the table in the lecture-notes: fuselage design part 1, see table 5.1) Figure 5.1 shows a cross-section of a seat in economy class. Appendix D.1 gives a detailed catia drawing of the passengers' seats.

	Short range	Short range	Our aircraft
Seat width	16 -18 in	0.40-0.46 m	0.48 m
Seat pitch	30 – 32 in	0.76-0.81	0.83 m
Aisle Width	> 15 in	0.38 m	0.66 m
Aisle Height	> 60 in	1.53m	2.40 m
Lavatories/passenger	1/ (40 -50)		
Total lavatories			4 toilets
Galley volume/passenger	1 ft^3	0.0283 m^3	1m wide, cabin height high. (about $8m^3$)
Total galley volume		5.38 m^3	6 m^3
Baggage/passenger	40 lbs	18.18 kg	20 kg
Total baggage (passengers + 6 crew)	7840 lbs	3563 kg	3920

Table 5.1: Cabin-related measurements in the fuselage.

5.1.2 Fuselage cross-section

In order to find the rest of the cross-section of the fuselage, some structural thickness is required. So if we assume a wall thickness of 8 cm for isolation and structural parts, a floor panel thickness of 12 cm to support the seats and a cargo compartment height of 1m15, then, using an exact circular exterior hull, the radius of the fuselage can be found. These measurements, and more needed to define the cabin layout are found in table 5.2. Appendix D.2 gives a detailed fuselage cross-section in Catia.

	B737-800	Our aircraft
Floor thickness		0.12 m
Cargo compartment height	1.20 m	1.15m
Aisle height	2.2 m	2.4 m
Fuselage inner diameter	3.50 m	4.0 m
fuselage thickness		0.08 m
Fuselage outer diameter	4.00 m	4.16 m
Total width of cabin floor: 6 seats + 1 aisle		3.90 m

Table 5.2: Cabin-related measurements in the fuselage.

5.2 Fuselage side-cross-section layout

5.2.1 Emergency exits

Following the rules of FAA and JAA regulations for 190 passengers, there should be 2 type I exits, 2 type III exits and 1 tail cone ventral exit. This gives 191 credits (179 + 12 for the tail cone) for passengers. These requirements are set and cannot be played with. For optimal evacuation purposes, the two type III exits were placed next to each other over wing. And in order to make the evacuation go smoothly, one seat was removed from each side of the cabin, in between the Type III exits. Doing a seat count now comes to 31 rows of two times 3 abreast, and 1 row of two times 2 abreast. This gives 31*6+1*4=190 passengers, just as the requirements said. Furthermore we got the requirement that each pair of type I exits must have 1 flight attendant nearby. Given that we already found that we needed 4 attendants, this should not be a concern.

Now, from the regulations of JAA, part CS 25.807 on Emergency exits:

> *(a) Type. For the purpose of this CS–25, the types of exits are defined as follows:*
> ***(1) Type I.*** *This type is a floor level exit with a rectangular opening of not less than 61 cm (24 inches) wide by 1·22 m (48 inches) high, with corner radii not greater than one-third the width of the exit.*
>
> ***(3) Type III.*** *This type is a rectangular opening of not less than 51 cm (20 inches) wide by 91 cm (36 inches) high, with corner radii not greater than one-third the width of the exit, and with a step-up inside the airplane of not more than 51 cm (20 inches). If the exit is located over the wing, the step-down outside the airplane may not exceed 69 cm (27 inches).*
>
> ***(5) Ventral.*** *This type is an exit from the passenger compartment through the pressure shell and the bottom fuselage skin. The dimensions and physical configuration of this*
> *type of exit must allow at least the same rate of egress as a Type I exit with the airplane in the normal ground attitude, with landing gear extended.*

5.2.2 Cabin Floor-plan

From 5.1 we determined the pitch between the seats. Now, using this pitch, the total pax number, the emergency exit layout and the galley volume, we can determine the total length of the cabin.

Using the 190 passengers, and an average of 50 passengers per toilet onboard, we get that this aircraft should have 4 restrooms. Also: 1 restroom is about 1 meter by 1 meter we also previously determined a 3-3 cabin layout would be optimal. So if we divide the total number of passengers by 6, we get the total number of rows we need to sit them on.

		Aircraft length
Seat pitch	0.83 m	
Number of rows	190/6	32 rows
Total seat length	0.83 m*32	26.6 m
2 Exit type 3	2 * 0.51 m	1.02 m
Passenger area length		27.6 m
2 times 1 row of toilets	2*1 m	2 m
galleys	1 m	1 m
2 exit type 1 + 30 cm clearance on doorframe	2*(0.6m+0.6)	2.4 m
Total cabin length		33 m

Table 5.1: Cabin-related measurements in the fuselage.

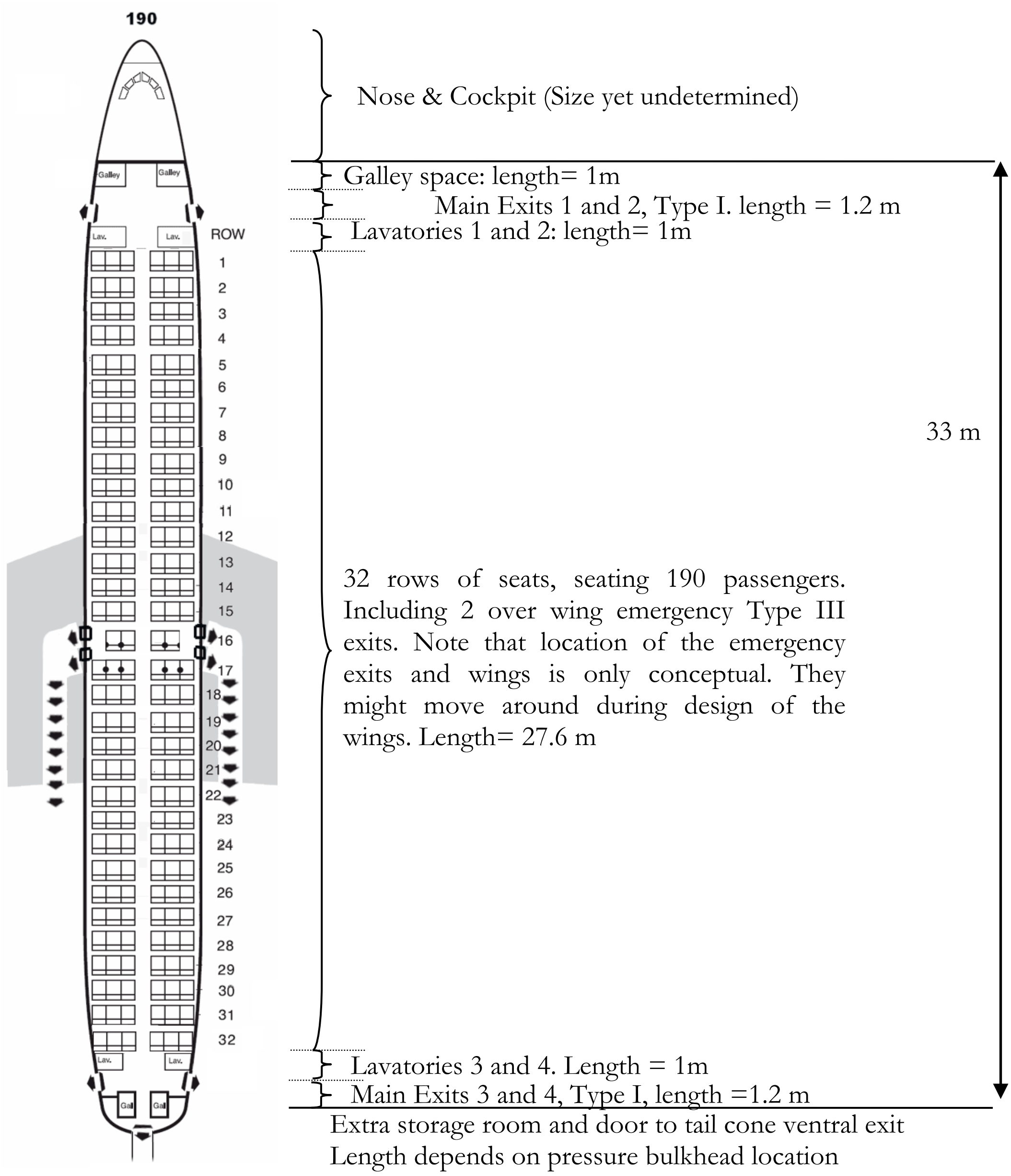


Figure 5.3: Cabin floor plan of the fuselage (not to scale).

5.2.2 Cargo Floor-plan

Now the passenger part is designed. The only thing left to design (in the payload section of the fuselage) is the location of the baggage. This can be done simply by multiplying the number of passengers by the maximum allowed volume of their suitcases. We assume each passenger can only bring 1 piece of luggage. Usually, luggage sizes are limited to 80 cm by 60 cm by 40 cm. this gives a volume of 0.192m^3 per passenger. Multiplying this by the amount of passengers (being 190, the crew is expected not to bring luggage to the airplane, and if they do, they should store it in the galleys or storage bins inside the aircraft) gives a total cargo volume of 36.48 m^3, or rounded off with an extra of 1m^3 for small mail or other documents gives 38 m^3 of cargo to be transported. A detailed view from the cargo compartment and necessary sizes can be found in appendices D.2 and D.3

In our cross-section we included the cargo area of the airliner. To shorten turnaround times, it is handier to include the luggage in so-called luggage carts or containers. For this aircraft, a luggage container was designed with a storage sizes given in the appendices mentioned before. This gives a total volume of $2m^3$ per cargo container. Dividing the $38m^3$ into the luggage containers results in the need for at least 19 containers. When also keeping in mind that the wing-crossing is cutting right through the cargo compartment, the latter can be designed optimally from the center out. A detailed side-view can be found in appendix D.3.

5.2.3 Design flexibility

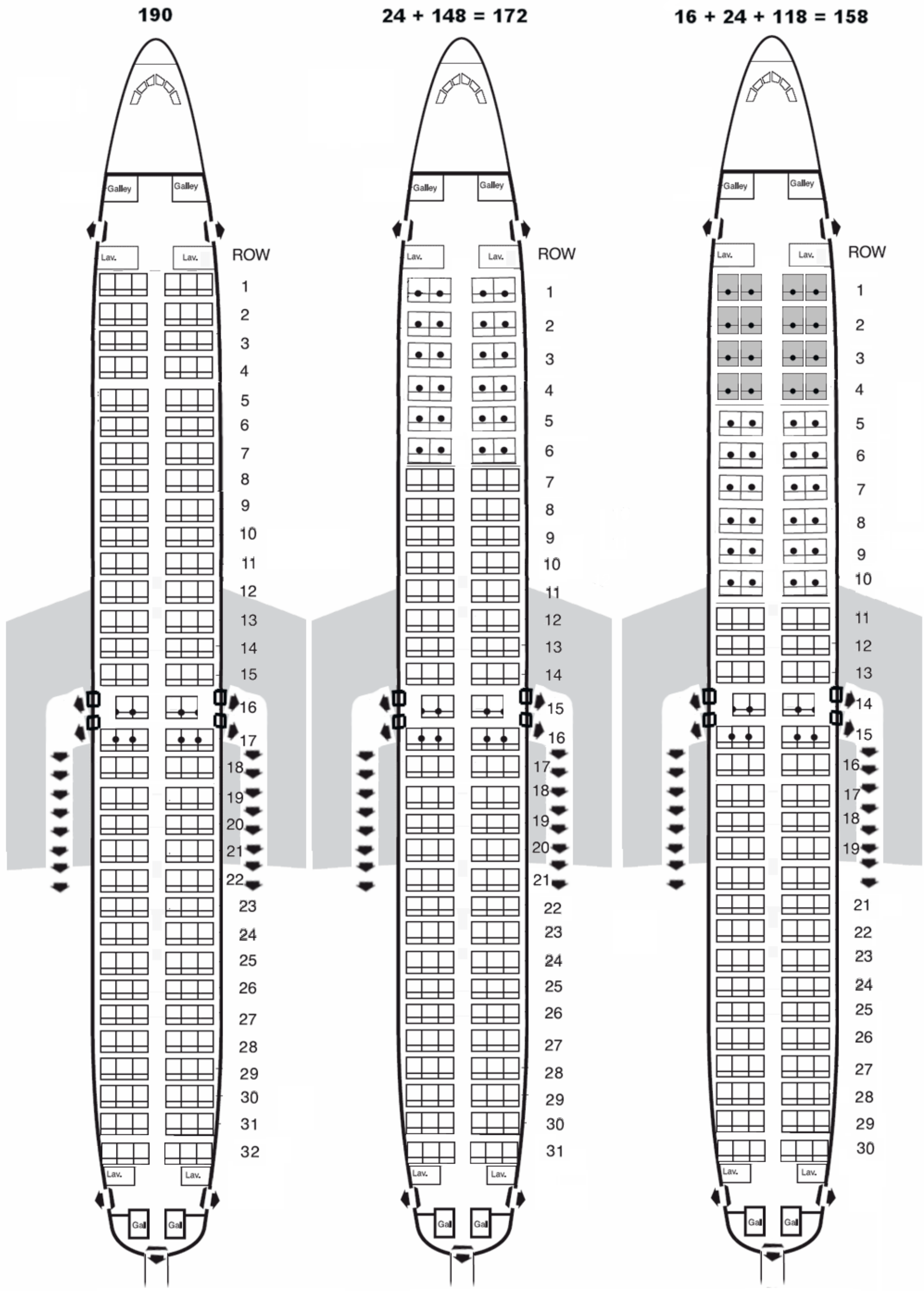


Figure 5.4: Cabin floor plan flexibility.

In order to show the flexibility of the chosen design, several floor plans have been made. One is dense economy, seating the required 190 passengers, one is 2-class: economy and business class, seating 172 people from which 24 first class passengers. And finally, a 3-class configuration, with

16 first class, 24 business and 118 economy seats, adding up to a total of 158 passengers. A layout of these floor plans can be found in figure 5.4. If required, this total passenger space could be converted to an all-cargo area, and then some exits could be removed. Resulting in more cargo space, and less weight.

5.2.4 The Cockpit

Nose
Using the different segments of the nose (cockpit, bulkhead, cockpit cabin room) the nose was designed from the inside out approach around the pilot.

Pilot
It is first necessary to have a clue of anthropometric data (Usually the average length of the pilot's lies between 1.66 -1.86 m) of the pilots for visibility issues. It is given from slides on BB that the height of the eyes of the pilot from the cockpit floor is about 44 inch or 1.1178 m. the captain seat- arrangement to the nose bulkhead is from slides BB around 1.18 m, this leaves a distance in the flight deck of 2.5 - 1.18 = 1.32 m for flight the inspector's seat and a crew wardrobe. After that the pilot's eyes are used as main point of reference. This determines all the angles necessary for the visibility. The main angles are described below.

The overnose angle
The overnose angle is determined by using this formula: Alpha_overnose = alpha_approach + 0.04 V_approach (V in Km/hr) (source Raymer). Assuming an approach speed of 252 km/h (referring to other aircraft since the approach speed for this aircraft is not yet known), and alpha approach is usually as small as possible and around 5 degree, this gives an Alpha_overnose of 15 degrees.

The transparency grazing angle
This angle is the smallest angle between the pilot's line of vision and the cockpit windshield and should be higher than 30 deg to guarantee an undistorted view at the surroundings through the windshield. For this aircraft a value of 32 degrees was chosen.

The upward angle
The upward angle is normally around 20 degrees for non combat aircraft and this holds also for this aircraft.

The length of the nose Ln
For this aircraft, the overnose angle was chosen to be 15 degrees (see slide 7, fuselage design part II). Then since, the diameter of the fuselage is already determined, using the typical fineness ratio of 1.95 (Ln/d =1.2-2.5) and referring to similar aircraft, the length of the nose Ln can be estimated to be around 8m .

The overall flight deck length
Then using the typical values that the overall flight deck length of an aircraft with 2 members of crew should be 2.5 m. Now assuming a tip of the nose which is 1.5 m longer than the forward pressure bulkhead, this gives a cockpit of 4m. now by shrinking the forward 4m of the fuselage a total nose length of 8m can be obtained. The cross-sectional height of the cockpit is chosen to be 2.53 m which smoothes out to the 4.16 m of the passenger cabin cross-section. During the design of the cockpit, attention was paid to the fact that the cockpit has to have enough space to store the front gear. Which will, for now, be assumed to have a diameter of at least 60 cm? Finally, the door and exposed walls of the cockpit are 5 cm thick and designed to withstand any human-inflicted damage or an impact caused by a significant mass or bullet. (These considerations come from the JAR section 25.795).

5.2.5 The Tail

Using an assumed fineness ratio of 2.7 (typical values Lt/d = between 2.6 – 4 for Jet Transports and using a diameter of 4.1 m), the length of the tail cone Lt is 10.66 m. This is done by taking into account the Tail cone angle (divergence angle) <= 24 deg (for Jet transports this value lies between 11 and 16) and the rotation angle of 14 degrees as specified in the regulations.

This rotation angle follows from aircraft rotation requirement and is strongly affected by the length and positioning of the landing gears.

5.2.6 The Landing gear

Since this is a medium-sized commercial jet, the standard tricycle will be used. The nose gear will retract in the nose of the aircraft, resting below the cockpit for the larger portion of the mission / flight. The main gear will have roots in the wing structure, and will retract between the aft-cargo compartment and the center wing box. The two wheel-wells will be separated by a belly-beam, which in turn prevents bending of the cabin. Another advantage of aircraft with the typical tricycle layout are easier for handling on the ground, have more visibility during take-off, and reduce the possibility for the aircraft to tip over its longitudinal axis, damaging a wing. A detailed front and side-view of the landing gear clearance angles and locations can be found in appendices D.3, D.4 and D.5

5.2.6 Tail planes & wings

For now, an assumption has been made that the wings have a root chord of 7 m. This assumption directly affects the cargo volume. The wings have been placed with the 1/4th cord line in the center of the fuselage's (and tails) length. This should be about the same position as the center of gravity of the aircraft. The tail-planes themselves are going to be designed in further detail in a later release of this report, when the control and wing-design is handled. For now, assumptions will be made that were derived from reference aircraft. The now-assumed values can be found in the appendix, but for easiness, they are summarized below in table 5.2.

	Reference aircraft		Our aircraft
wingspan	B 737-800	35.7 m	35 m
Wing crossing area on fuselage	B 737-800	8 m	7 m
Tail height	B 737-900	12.5 m	12 m
Horizontal stabilizer	B 737-800	14.3 m	15 m
Aircraft height	A320 -200	11.8 m	12 m
Engines clearance from ground	B 737-800	50 cm	60 cm

Table 5.2: Estimated values for the tail-planes and wings.

:

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PDF BB THE PRANDTL WING Prof. Aldo Frediani Pisa University- Italy

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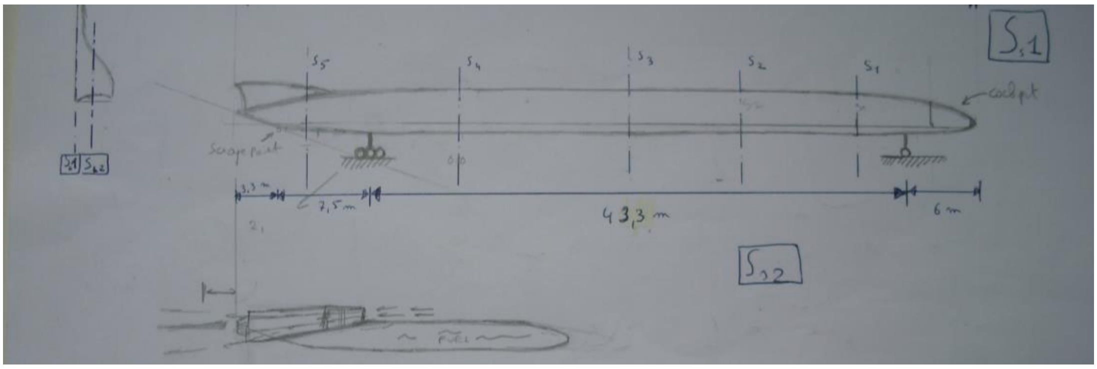
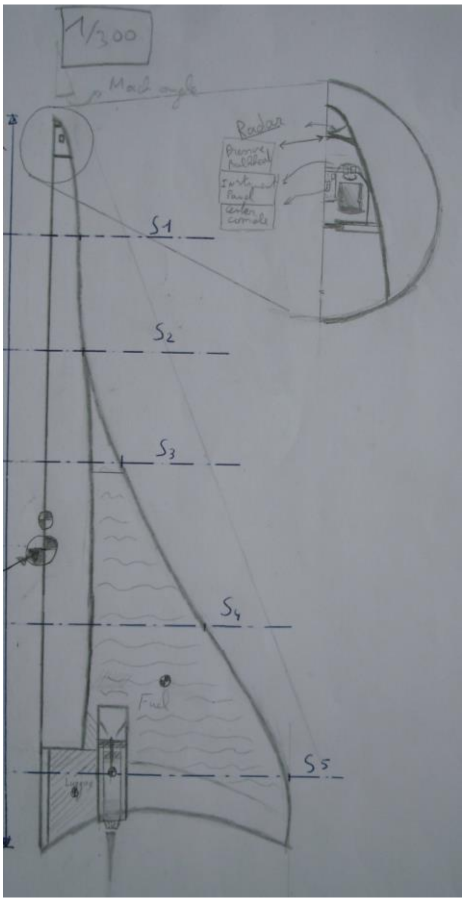
Appendices

Appendix A: Concept Designs

A.1: Concept 1, Blended winged body





A.2: Concept 2, Conventional design 1.

A.3: Concept 3, Conventional design 2.

See the following pages

Appendix B: Table of reference aircraft and their characteristics

		Length [m]	engines	Cockpit crew	nr passenger (1-class)	Range (at MTOW) [km]	range (km)
airbus	**A320-200**	44,51	2	2	180		5600
Airbus	**A321-200**				220		5600
Boeing	**737-800**	39,5			189		5670
Boeing	**707-320B**	46,61	4	3	202	10650	6920
Boeing	**727-200**	46,7	3	3	189		4450
Airbus	**A350-800**	60,7			270		15400
Douglas	**DC-8-63CF**	57,1	4	3	180		3445
Ilyushin	**Il-62**	53,12	4	5	186		9,2
Shanghai	**Y-10**	42,93	4	5	178		8300
Tupolev	**Tu-114 Rossiya**	54,1	4	5	220		6200
Tupolev	**Tu-154**	48	3		180	2500	
Boeing	**757-200**	47,32	2	2	234	7,222	
Boeing	**747-400**	70,7	2	4	450	12491	
McDonnell Douglas DC-9	**DC-9-50**	49,7			135		3030
Boeing	**737-400**	36,5	2	2	168	4204	
Yakovlev	**Yak-42D**	36,38	3		120		41000
Lockheed	**L-1011-1**	54,2	3		253	7420	
Airbus	**A300B4**	54,08	2	3	266	6670	
Airbus Beluga	**A300-600ST**	56,15		2	47000t	2779	
McDonnell Douglas	**MD-81**	45,1			172	2910	

		Cruise altitude [m]	Service ceiling [m]	Cruise speed [Mach]	max cruise speed [Mach]	Take off distance [m]	Landing distance MLW [m]	Empty weight [kg]
airbus	**A320-200**	12000	12000	0,82		2180		48200
Airbus	**A321-200**	1200		0,82		2180		
Boeing	**737-800**	12500		0.785	2525			41413
Boeing	**707-320B**			972 km/h		3280	1813	66406
Boeing	**727-200**			.81		1768	1585	
Airbus	**A350-800**	13100		0.85				
Douglas	**DC-8-63CF**							6636
Ilyushin	**Il-62**		12000					67500
Shanghai	**Y-10**		12000					58120
Tupolev	**Tu-114 Rossiya**		12000	770 km/h				93000
Tupolev	**Tu-154**		12100					50700
Boeing	**757-200**		12800	0.80				
McDonnell Douglas	**DC-9-50**			898 km/h				
Boeing	**737-400**		11277,73	0.74	0.82			33200
Yakovlev	**Yak-42D**		8800		810km/h			
Lockheed	**L-1011-1**		11000	0.86	0.86		101867	101867
Airbus	**A300B4**			0.78	0.82			90060
Airbus Beluga	**A300-600ST**							86000
McDonnell Douglas	**MD-81**			.76				

		MTOW [kg]	Maximum speed	Wingspan [m]	Wing Area [m²]	Wing aspect ratio	Wing Sweepback [degrees]	Height [m]
airbus	**A320-200**	93500		34,1	122,6		25	11,76
Airbus	**A321-200**							
Boeing	**737-800**	79010	Mach 0.82	35,7			25,02	
Boeing	**707-320B**	151320		44,42				
Boeing	**727-200**		.90 Mach	32,9				
Airbus	**A350-800**			64,8	443		31,9	17,1
Douglas	**DC-8-63CF**	161000	959 km/h	45,24	271,9			13,11
Ilyushin	**Il-62**	165000	900 km/h	43,2	279,5			12,35
Shanghai	**Y-10**	110227	639 km/h	42,24	244,5			13,42
Tupolev	**Tu-114 Rossiya**	175000	870 km/h	51,1	311,1			15,44
Tupolev	**Tu-154**	99000	950 km/h	37,55	201,5			11,4
Boeing	**757-200**	115680		38,05	181,25	7,8	25	
Boeing	**747-400**	401300						
McDonnell Douglas	**DC-9-50**	54900		28,47				
Boeing	**737-400**	68050		28,9			25	11,1
Yakovlev	**Yak-42D**			34,88	150			9,83
Lockheed	**L-1011-1**	200000		47,3	321,1			16,9
Airbus	**A300B4**	165000		44,85	260			16,62
Airbus Beluga	**A300-600ST**	155000		44,84	122,4			17,24
McDonnell Douglas	**MD-81**			32,8				9,05

		Maximum landing weight [kg]	Maximum zero-fuel weight [kg]	Takeoff run at MTOW [m]	Fuselage Width [m]	Fuselage Height	Cabin width [m]	Cabin Height [m]	Cabin length [m]	Tail Height
airbus	A320-200				3,95		3,7			
Airbus	A321-200									
Boeing	737-800			2525	3,8	4.0 m	3,5	2,2		
Boeing	707-320B				3,76					
Boeing	727-200									
Airbus	A350-800				5,96	6.09 m	5,59			
Douglas	DC-8-63CF				3,73					
Boeing	757-200			2911			3,54		36,09	
Boeing	747-400									
McDonnell Douglas DC-9	DC-9-50									8.38 m
Boeing	737-400	56200	53100	2540	3,76	4.11 m	3,54	2,2		
Lockheed	L-1011-1	167000					5,7			
Airbus	A300B4						5,28			

Appendix C: Current Aircraft Parameters Table

Symbol	Parameters	Value	Unit
	General data		
b	Wing span	35	m
	Cabin characteristics		
	Cabin length	33	m
	Flight deck length	2.5	m
	Tail length	10,66	m
	Cabin length	25.34	m
	Maximum diameter	4.1	m
	Maximum cabin height	2.53	m
	Maximum width	4,1	m
	Aisle width	0.66	m
	Aisle height	2.35	m
	Wall thickness	0.08	m
	Chair width	0.48	m
	Chair Pitch	0.83	m
	Fineness	10.73	-
	Nose fineness	1.92	-
	After body fineness	2.56	-
	Overnose angle	15	Degrees
	Overside angle	35	Degrees
	Grazing angle	32	Degrees
	Upward angle	20	Degrees
	Divergence angle	19	Degrees
	Fuselage Characteristics		
	Total length	42.5	m
	Landing Gear Characteristics		
	Aircraft Wing geometry		
b	Wing span	35	m
S	Wing area		
A	Aspect ratio		
Λ	Wing sweep angle		
	Weights and loadings		
	Payload weight		kg
W_E	Empty weight		
W_{MTO}	Maximum take-off weight		
W/S	(maximum) Wing loading		
	Flight parameters		
h_{cruise}	Cruise altitude	11800	m

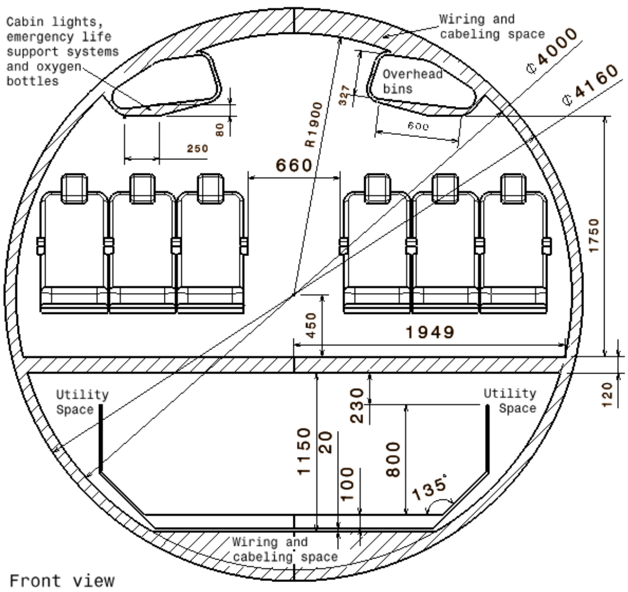
V_{cruise}	Cruise speed	0.82	Mach
$C_{Lcruise}$	Cruise lift coefficient		
C_{Lmax}	Maximum lift coefficient (take-off)		
s_{TO}	Take-off distance	2100	m
s_L	Landing distance	1650	m
	Range	5500	km

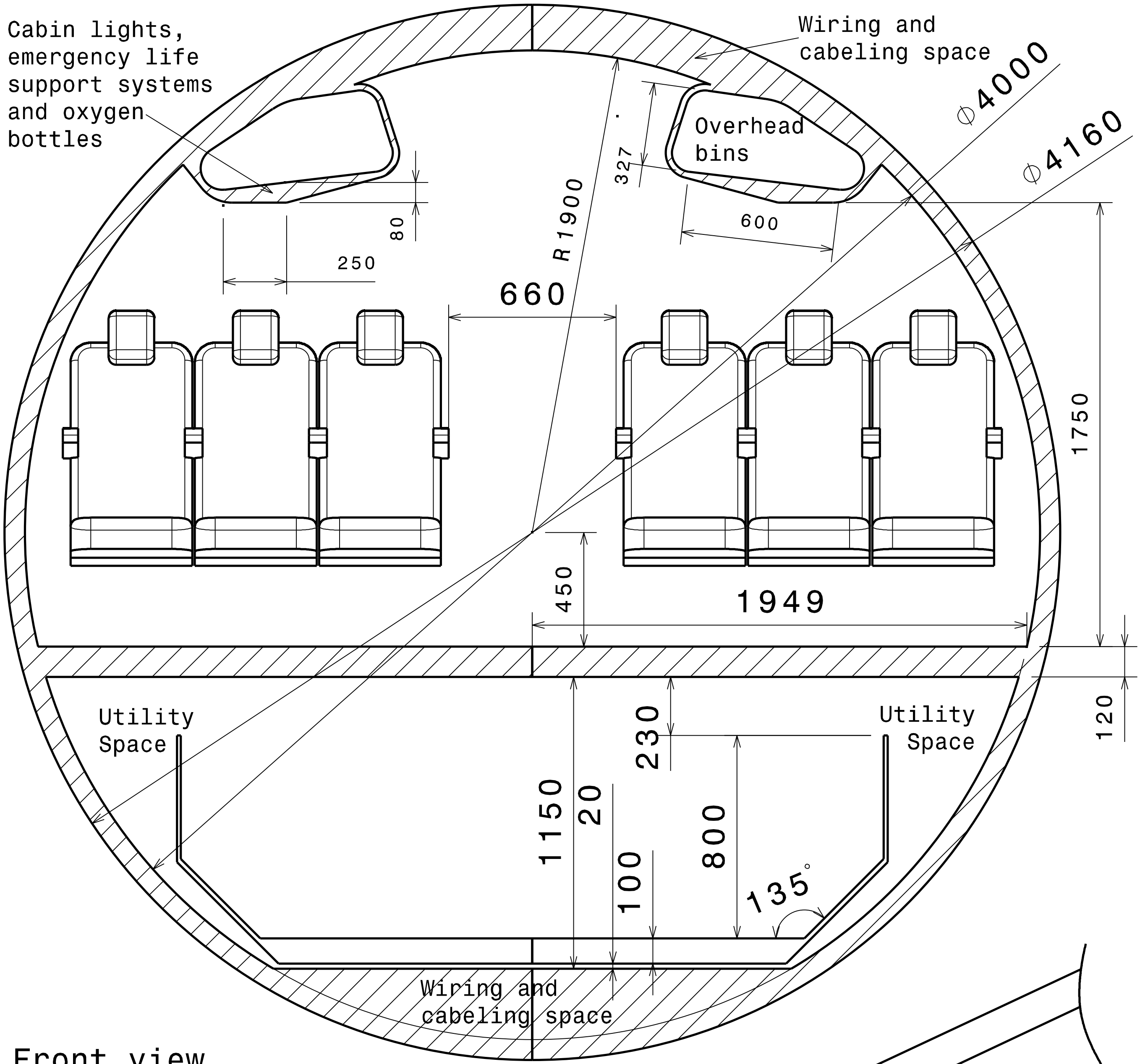
Appendix D: Aircraft Technical Drawings

See Catia-drawings on the next pages. These are the reference names that were given to them in the text:

- **D.1: Passenger 3-seat configuration.**
- **D.2: Fuselage cross-section.**
- **D.3: Fuselage side-view and landing gear approximation.**
- **D.4: Cockpit detail and 3-views, with crew seat locations.**
- **D.5: Fuselage front view and ground clearances.**

Note: some inconsistencies may exist between measurements in the table and measurements on the drawings and between different drawings. Especially in the cockpit section. Here it is accepted that the most detailed drawing on the part resembles the actual measurement values of that part.





Front view
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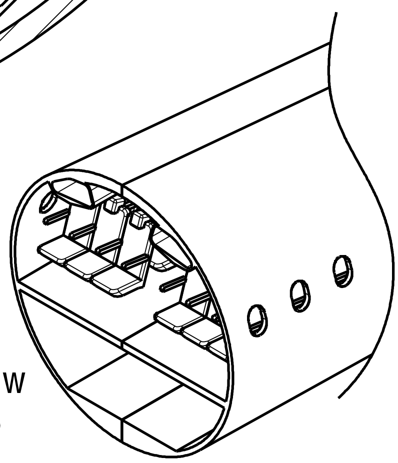

Isometric view
Scale: 1:100

Aircraft Design

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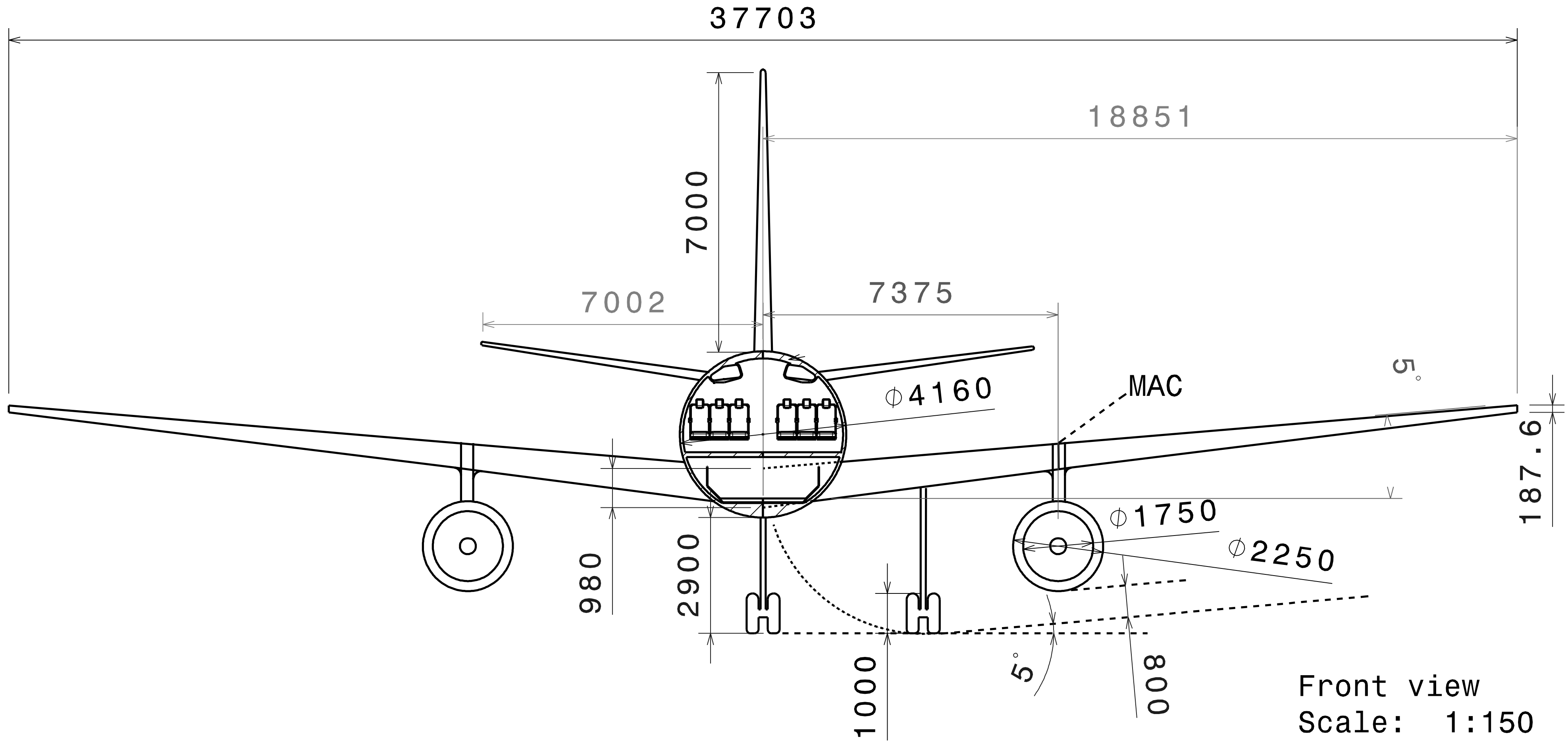
DESIGNED BY	DATE	SCALE 1:25 / WEIGHT(kg)	SHEET 1/1



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DRAWN BY Wout De Backer	DATE 05/12/2009	DRAWING TITLE Front View			
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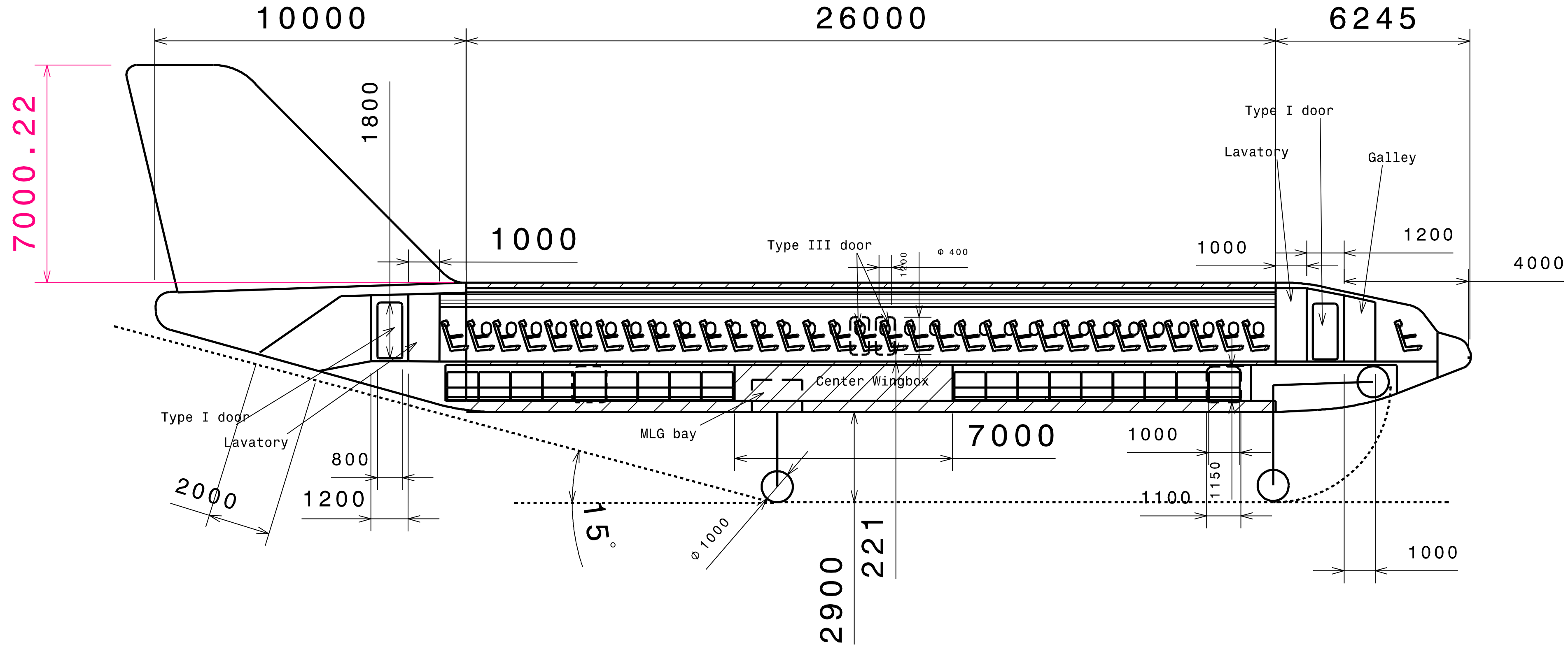
DESIGNED BY	DATE	SCALE 1:1	WEIGHT (kg)		SHEET 1/1



Front view
Scale: 1:200

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		DRAWING TITLE D.3:Fuselage side-view and landing gear approximation.			
DRAWN BY Wout De Backer	DATE 20/09/2009				
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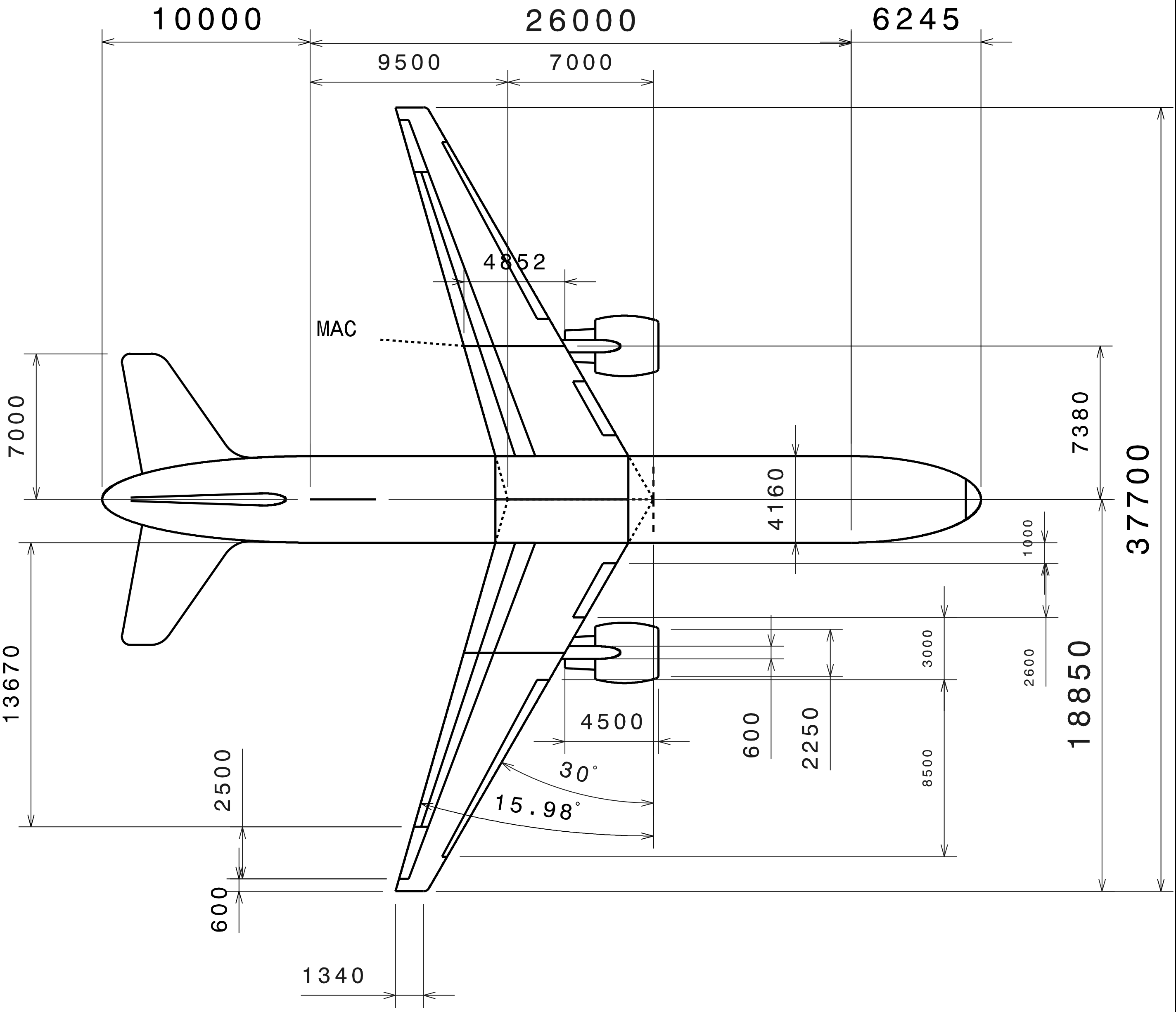
DESIGNED BY	DATE	SCALE 1:200	WEIGHT(kg)		SHEET 1/1



Top
Scale: 1:300

Aircraft Design

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DESIGNED BY	DATE	SCALE 1:1	WEIGHT(kg)		SHEET 1/1