Aircraft Design 1 – Fall 2020

***Assignment 1, Analysis of Requirements, Airworthiness and Fuselage Design***

Instance 1
Hours spent on assignment: 50 h

Aircraft type: Business Jet
Aircraft number: 127

**Table 1: Requirements Table**

| Requirement type | Value | Unit |
|---|---|---|
| Payload | 8 | Passengers + luggage |
| Max Payload Weight | 1300 | Kg |
| Range | 4000 | Km |
| Cruise altitude | 13,716 | m |
| Cruise speed | 800 | Km/h |
| Take-off distance | 1600 | m |
| Landing distance | 900 | m |
| Propulsion System | 1-2 | Jet |

*Figure 1: CAD Rendering of Aircraft Design*

**Table of Contents**

# 1. Introduction

The following report will discuss the early stages of the aircraft design process for a business jet with a given set of requirements. When starting any new aircraft project, there must be a specific function the aircraft will perform. The aircraft's function, or mission, along with an analysis of the aircraft's requirements will be discussed in chapter 2 of the report. Chapter 3 will focus on the aircraft reference database which will become an essential tool at all stages of the aircraft design process. Next, chapter 4 will discuss the conceptual design phase and concept generation for an aircraft that meets all the given requirements concluding with a selection of the best design idea. Chapter 5 will focus on the generation of the full fuselage layout using an inside out approach. Finally, the Appendices will provide technical drawings of the current design which are subject to change as the design process of the entire aircraft continues, as well as images conceptual design ideas.

# 2. Mission definition and Analysis of requirements

Before starting any new aircraft project, a proper market analysis must be performed to demonstrate the need for a new aircraft as well as a sustainable customer base for the product to maximize profits. There is no point of making the aircraft if there is nobody to buy the aircraft. For this report, it will be assumed that a full marketing analysis was performed by a marketing department and found the need for a new aircraft. After this step in the process, the purpose of the aircraft must be determined. The purpose of the aircraft is then used as a driving force to determine the necessary requirements to fulfil that function.

## 2.1. Mission Profile

For a typical business jet, its function is to transport small groups of people, including their luggage, from one destination to another. Figure 1 below shows a typical mission profile for a business jet

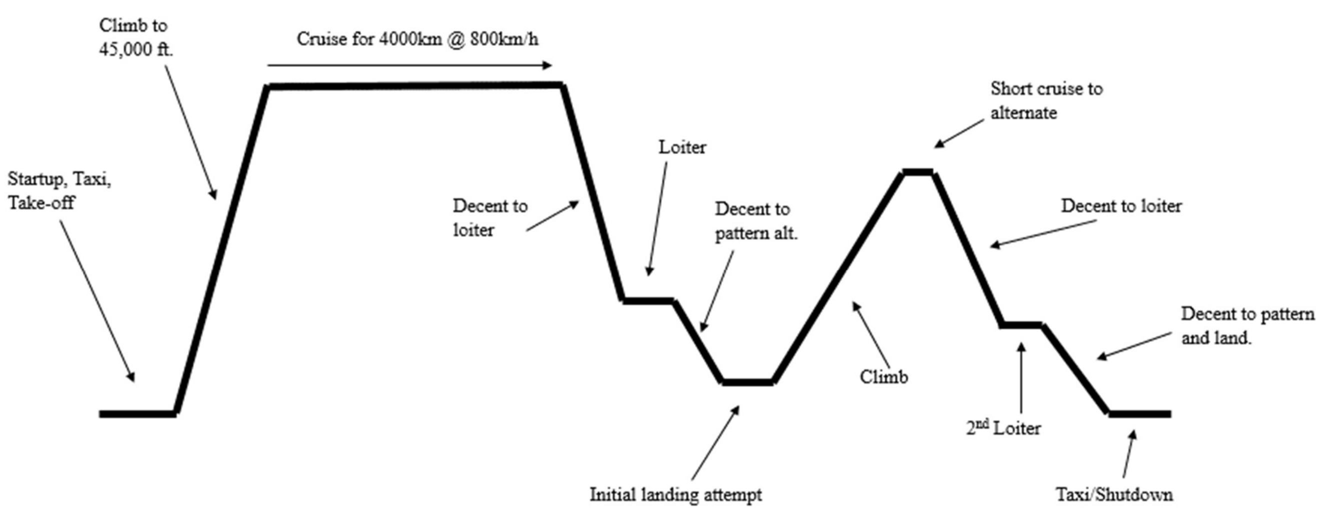




*Figure 2.1: Mission Profile*

The typical mission for our concept aircraft will be as follow, the aircraft will need to be able to be loaded without airport services from a stepped door, and have cargo or baggage loaded in a compartment aft of the rear bulkhead. The plane will hold up to two crew and 8 passengers. Once loaded, the plane will need to start without the use of ground equipment. It will be required to taxi for up to 45 minutes and do a full run-up. The aircraft will then take-off, clearing any obstacles, and climb to a cruising altitude of 45,000ft. While climbing the cabin will maintain a comfortable level of interior pressurization. At cruise, the aircraft will travel at 800km/h until it descends into loiter pattern for the destination airport. Taking into account the airport conditions may not be suitable for landing, the aircraft will make an attempt at landing, if unable it will then climb back to a reduced cruise height from 5,000 - 15,000 ft and descend to an alternate airports loiter pattern and land within the required distance. Once on the ground the aircraft will need to taxi to desired shutdown location and be unloaded without the help of ground services.

## 2.2. Requirements Analysis

After determining the function of the new aircraft, a set of requirements must be set to meet those needs. For this report, a set of requirements were given as a base to begin the design process. In this section, a complete critical analysis will be performed on the given requirements to understand how they will each affect the aircraft. Some additional requirements must also be assumed to properly configure the design.

### 2.2.1. Payload Analysis

For this configuration, it is given that the payload of the aircraft is 1300kg, but there are no requirements on the specific number of required passengers. Business jets are typically designed with the passenger's comfort in mind rather than fitting as many people as possible like typical commercial airliners. Therefore, by referencing data from similar aircrafts, an adequate number of passengers can be assumed. Below is a table comparing the new aircraft to two other aircrafts with similar payload requirements.

| **Reference Data** | **Cessna Citation Latitude** | **Embraer Legacy 450** | **Our Aircraft** |
|---|---|---|---|
| Max Payload (kg) | 1258 | 1325 | 1300 |
| # of Pax | 9 | 9 | 8 |
| Crew | 2 | 2 | 2 |
| Baggage Volume ($m^3$) | 3.6 | 4.2 | 4 |

*Table 2.1: Reference Payload Data*

Both the Cessna Citation Latitude and Embraer Legacy 450 can hold 9 passengers. However, to maximize comfort of the passengers, the design will only accommodate 8 passengers and 2 crew members. The payload requirement must account for the weight of each passenger and their luggage plus the weight of the luggage for the crew. Since this business jet is not a general aviation aircraft, the weight of the crew members will be accounted for in the basic operative weight of the aircraft. Therefore, by assuming an average passenger weight of 200lb or 90kg, the weight of the passengers will total 90*8=720kg. The luggage weight is assumed to be 50lb or 23kg per passenger and crew member, which will total 23*10=230kg. Combing these weights will give a payload of 950 kg, which is well below the maximum payload weight. The extra weight will allow the potential for each passenger to bring additional luggage such as golf clubs, etc.

The payload will also drive the configuration of the cabin, and the storage requirements. A cargo volume of 4m$^3$ was assumed for the aircraft based on reference data from figure 2. Also, since a business jet is being designed with passengers as the main payload, the cabin must be comfortable for them which will driving sizing requirements. An analysis of the fuselage sizing requirements will be further examined in section 5.

### 2.2.2. Propulsion Analysis

The given requirements state that the powerplant of the aircraft must be a jet engine. However, the requirements do not specify how many jets are required for operation, but they must be capable of a cruise speed of 800 km/h. Conventional business jets operate with two jet engines located in the rear. Another alternative is to use only one engine on the top of the aircraft.

*Figure 2.2: Conventional Two Engine Jet*

*Figure 2.3: Non-conventional Single Engine Jet*

Figure 2.2 shows the conventional engine figuration on a business jet with two engines mounted on the tail. This method is extremely popular and will be easy to replicate. Figure 2.3 shows an image of a Cirrus Vision SF50 which only uses one jet engine on top of the aircraft. This propulsion configuration is typically only seen on light jets, but it has the potential to meet the design requirements. However, this configuration will likely add complexity to the tail configuration and may be difficult to certify since there is only a single engine. The propulsion choice will be discussed further during the conceptual design phase in chapter 4.

### 2.2.3. Certification Analysis

To obtain proper airworthiness certifications, the aircraft must comply to the standard regulations set by government associations. This aircraft will adhere to the Federal Aviation Regulations (FAR) set by the Federal Aviation Administration (FAA). For aircrafts over 12,500lb, they must adhere to FAR part 25. Although weights have not yet been estimated, it will be assumed that the aircraft weighs more than 12,500lb and follows this set of regulations. If the aircraft is found to weigh less than this value, the specific set of regulations to follow will be changed accordingly.

### 2.2.4. Performance Analysis

Certain performance characteristics were given in the preliminary list of requirements, which will impact the overall design. For example, the aircraft must be capable of a range of 4,000km during cruise which will drive the amount of fuel the aircraft must carry adding to the weight.

The take-off distance is specified to be 1600m, which is the length of runway needed to lift off and climb to a height of 35 feet. This value has a direct relationship to the wing loading, airport altitude, and ground field roughness. This is a critical value to know for the aircraft because even if the aircraft is able to land at an airport, it may not always be able to take-off since the take-off distance is larger than the landing distance.

The landing distance is given as 900m which is defined as the length of runway needed to descend from a height of 50ft, touchdown, and arrest. Similar to the take-off distance, the landing distance will be dependent on the wing loading for the aircraft, the stall speed, and the surface of the landing field. Also, wind and other weather conditions must be factored into this value to assure the aircraft can land and safely stop in the prescribed distance even during wet conditions.

### 2.2.5. Additional Requirements

Some requirements were not specified but must be included when designing the aircraft. Based on reference aircraft data, the operative altitude is assumed to be 13,716m, which will require cabin pressurization. Cabin pressurization will bring about certain structural requirements and added weight since the fuselage must be properly stiffened and supported.

Based on the mission profile, this aircraft must be able to loiter since it accounts for two steps in the event of a missed landing attempt. Therefore, loitering will require extra fuel and added weight to maintain safe operation of the vehicle. In visual flight rules, regulations require 30 minutes of extra cruise fuel to reach the next airport.

Since this business jet is designed for the comfort of the passenger, it will be important to add a lavatory and provide adequate cabin space, which will be further analyzed in section 5.

Cost is also a very influential driving requirement for an aircraft design, but cost analysis is out of the scope of this assignment.

### 2.2.6. Driving Requirements

The main requirements for the design process are the range, speed, and payload. The speed requirement will have a direct impact on the type of propulsion system needed for the aircraft which will add to the weight. Range will have an impact on the fuel quantity and weight, and the payload will also drive the weight requirements. More importantly, the type of payload will determine the cabin layout which will be examined in section 5.

# 3. Reference Aircraft Data Collection

Reference aircraft data is an essential tool to comparing a design concept to other designs that have already been produced. This data is very useful for estimating missing requirements or to make sure that given requirements will comply with proven aircraft designs. Some of this data includes weight requirements, types of propulsion systems, and aircraft and cabin dimensions. All current aircraft data is summarized in Appendix 2. It is important to note that some columns have missing data which means certain values could not be found. Also, the reference data will be updated for each assignment based on different design characteristics that will be needed further on in the design process.

| | | **Occupancy** | | **Weight** | | | |
|---|---|---|---|---|---|---|---|
| Manufacturer | Type | Crew | Passengers | MTOW (kg) | BOW (kg) | Max Payload | Fuel (kg) |
| Cessna | Citation II | 2 | 8 | 6,849 | 3,923 | 1,066 | 2,254 |
| Embraer | Phenom 300E | 2 | 10 | 8,150 | 5,344 | 1,196 | 2,428 |
| Bombardier | Learjet 60 | 2 | 8 | 10,659 | 6700 | 1011 | 3588 |
| Bombardier | Challenger 300 | 2 | 8 | 17622 | 10818 | 1,588 | 6418 |
| GulfStream | G100 | 2 | 7 | 11,181 | 6,515 | 1195 | 4248 |
| Honda | HA-420 HondaJet | 2 | 7 | 4,854 | 3303 | 635 | 1290 |
| Bombardier | Learjet 45 | 2 | 9 | 9,752 | 6,300 | 1002 | 2750 |

*Table 3.1: Sample Aircraft Reference Data from Appendix 2*

# 4. Concept Generation and Selection

## 4.1 Concept Generation

For this assignment we created 3 concepts of business jets, a conventional T-tail concept, a slightly unconventional V-Tail concept, and then an unconventional wing tip rudder design with canard surfaces. A more detailed description of these designs is listed below.

- Conventional T-tail Configuration
  - Tail plane configuration: Conventional T-Tail
  - Engine configuration: Tail Mounted
  - Wing configuration: Low

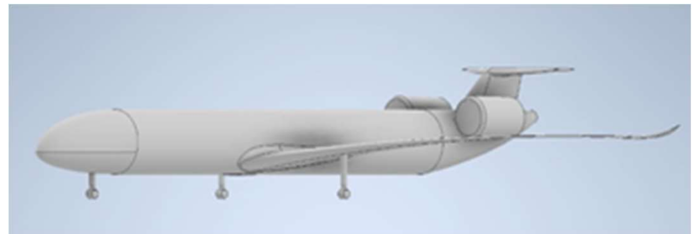

*Figure 4.1: T-tail Configuration*

- Less Conventional V-Tail Configuration
  - Tail plane configuration: V-Tail
  - Engine configuration: Tail mounted between ruddervators
  - Wing configuration: Low

*Figure 4.2: V-Tail Configuration*

- Unconventional Wing Tip Rudder Configuration
  - Tail plane configuration: Tailless, wing tip rudders
  - Engine configuration: Tail Mounted
  - Wing configuration: Mid wing with canard

*Figure 4.3: Wing Tip Rudder Configuration*

For each of these designs the same basic fuselage sections will be used, they will include a cockpit with seating for 2 pilots and a cabin seating 6-8 passengers this will include seats that are 3 rows of 1x1 seating. These seats can rotate to face rearward, sideways, or backward. The 8 passenger concepts will include a couch with seating for 2 passengers.

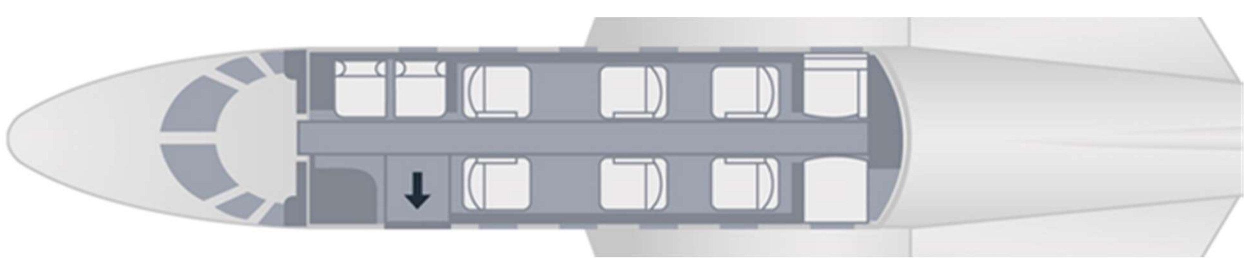

*Figure 4.4: Basic Cabin Configuration of each concept.*

When designing concepts for our aircraft, we decided that due to cabin space requirements a low wing configuration or a rear mounted wing configuration would be best to maximize the cabin space. It would not be feasible to have a mid-wing or a high-wing configuration for this type of jet due to the already limited space. The mid-wing would bisect the cabin and remove most of its usability and the high wing would restrict and already limited cabin height due to the necessity of a wing box.

In the next sections, each concept will be explained in more detail.

### 4.1.1. T-Tail Configuration

*Figure 4.5: T-tail Configuration*

*Figure 4.6: Cessna Citation CJ4*

The T-tail design is tried and true, a proven concept that has been around and been successful for decades. The T-tail does increase drag as compared to out other designs but offers more control and if designed correctly offers forgiving stall characteristics and adequate feedback to the pilots. The T-tail design with a low wing allows for adequate cabin area, and easy loading. It would also have reduced complexity of the wings and wing box as they can be placed below the cabin floor. This would increase drag slightly but offer a more comfortable cabin space and consistent floor height down the length of the aircraft.

### 4.1.2. V-Tail Configuration

*Figure 4.7: V-Tail Configuration*

*Figure 4.8: Cirrus Vision SF50*

The second Concept we came up with was a V-Tail design, from our research we did not find a business jet which has used this design, it is generally used for general aviation aircraft and we modelled our design and engine configuration off of a Cirrus Vision Jet with one single engine placed in the inner section of the V-tail. This design is limited in the fact that it only has one engine but has the potential to be a quieter and more efficient option. Due to the absence of a rudder control surface there would be less drag on the body of this aircraft. The V-tail would instead act as a ruddervator, performing the duties of both rudder and elevator. This design is mostly limited by the loss of control at lower speeds such as take-off and landing, and the fact that it only has one engine which may affect certification and range.

### 4.1.3. Unconventional Wingtip Rudder Configuration

*Figure 4.9: Wing Tip Rudder Configuration*

*Figure 4.10: Beechcraft Starship*

For the third and final concept, we chose to model our concept off the Beechcraft Starship, this design is theoretically more efficient since the canard and main wing both produce a lifting force, however it is very complicated to make sure the canard stalls prior to the main wing. The Starship used a Canard that could adjust its sweep angle to account for this, and make sure the aircraft was controllable at cruise as well as low speeds.  While this design could lead to increased efficiency and range, past examples of similar configurations lead to complex electronic controls and structures that out weight the potential benefits.  The Piaggio Avanti also uses a canard design and rear wing but has a T-Tail to assist with yaw and pitch control. Our design would depend on the canards producing pitch moments and the wing tip rudders to produce a yaw moment. These wing tip rudders would also add serious complications to the wing design, while they would increase efficiency, the weight and complexity of the design probably would not be feasible for this course.  The wings of this tailless design would need to be shorter and have an increased chord compared to the other designs to account for the structural requirements of the wing tips.

### 4.2 Concept Selection

While we were tasked to make 3 concepts one of which considered to be unconventional, the T-Tail design is the most realistic and suitable design for this project. From our research, the T-tail design is the most used in the business jet class of aircraft, and for good reason. The T-tail would offer a flat floor, and good stability at lower speeds while still offering efficiency at cruise. The stall characteristics of this aircraft would be more reliable than the other concepts. And most of all, this concept would offer familiarity to the customer.

Concept 2, V-Tail configuration is a thoughtful design and comes with reduced noise and drag, but the limited engine size and low speed stability makes it a difficult concept to support with respect to this project. We were able to find smaller general aviation aircraft with this design, but references for larger business jets with a centrally mounted engine and V-tail were to difficult to find and draw conclusions from.

The third concept was the most unconventional of the three, the tailless design coupled with a mid-wing configuration would significantly decrease the drag on the aircraft and allow it to generate more lift due to the canard surfaces working in tandem with the main wings. This design has been sued before in the Beechcraft Starship and a similar design was used in the Piaggio Avanti, however that aircraft also had a T-tail. While tailless aircraft have been created and flown before, the complexity of their stability and control are out of the scope of this project. Large companies still struggle with the creation of these aircraft and by the time they are completed the drawbacks of the design usually outweigh the benefits.

There were several unique business jet concepts however, most of the aircraft we researched had a T-tail or Cross-tail design. This is not to say the other designs are not unattainable, but for the scope of this class and in the sense of business proposals and revenue the T-tail design would be the most practical, cheapest to manufacture and maintain, and would offer customers the comfort and stability of a familiar platform. Pilot would need less training for this aircraft as well which could cost the customers more money in addition to the cost of the jet itself.
Overall, we decided the most worthwhile configuration to pursue in the scope of this project would be the T-Tail configuration.

# 5. Study and Generation of Complete Fuselage Layout

In order to construct a complete fuselage layout, an inside-out approach was used to generate the cabin, the nose, and the tail sections. Different design aspects such as cabin dimensions and layouts were considered based on reference aircrafts. This section will also discuss the landing gear, wing, tail, and engine configurations briefly since exact dimensions are not yet known for these components.

## 5.1. Cabin Design

### 5.1.1. Cabin Cross Section Generation

The fuselage design is driven by the payload which is the passengers. While the cabin must be able to hold 8 passengers, a business jet must be able to do so comfortably. This means passengers should have access to larger chairs than those on commercial airliners, more legroom, and more room to move about the cabin. During this phase, two different cross section designs were considered. Similar concepts can be seen below in figure 5.1.


*Figure 5.1: Typical Business Jet Cabin Cross Section*

The image on the left of figure shows the cross section of the cabin on a Beechcraft Hawker 850XP in which the floor sits lower than the seats. This same concept is widely used on other business jets including the Embraer Phenom 300E and the Cessna Citation XLS+. It is mainly required for a fuselage of a smaller diameter to allow a larger aisle height for passengers to walk in the cabin. However, this design limits the headroom above each seat and may make the cabin feel too crammed for passengers. Therefore, a fuselage cross section like that of a Cessna Citation Latitude was chosen will a fully horizontal floor. This layout will make it easier for passengers to move around the cabin and get in and out of their seats. A flat floor will hopefully limit the size of the fairing as well as drag since the landing gear will have more room to be stored under the floor. Also, it was determined that the fuselage would have a circular cross section since it is easier to manufacture and easier to pressurize.

### 5.1.2. Cabin Front Cross Section Specifications

Chair dimensions were needed to properly size the fuselage around the payload. The chairs were designed according to anthropometric data, but the minimum required dimensions were increased to maximize the comfort of the passengers. The size of the aisle needed to meet certain requirements. According to FAR 25.815, an aircraft with a passenger seating capacity of 10 or less requires an aisle width of at least 12in or 0.3m. The aisle was designed to be 0.5m to follow regulations and allow passengers plenty of room to move freely around the cabin.

Using the width of the two chairs and the aisle, the inner fuselage diameter was chosen to be 1.98m. To account for the fuselage skin, frames, and insulation panels in a pressurized aircraft, the inner diameter must be increased by 4% resulting in an outer fuselage diameter of 2.06m. A picture of the front fuselage cross section can be seen in figure 5.2, and the corresponding dimensions can be viewed in table 5.1. A completely annotated and scaled drawing of this fuselage cross section is provided in appendix 4.1.

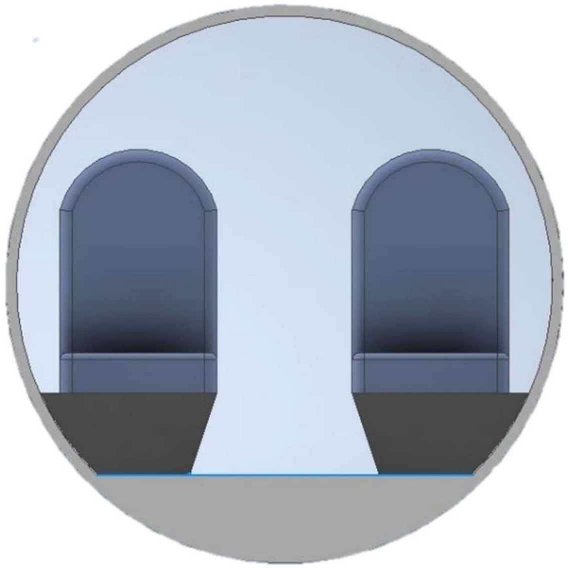

*Figure 5.2: Typical Business Jet Cabin Cross Section (Not to scale)*

| Technical Specs | Cessna Citation Latitude | Our Aircraft |
|---|---|---|
| Cabin Height (m) | 1.8 | 1.69 |
| Aisle Width (m) | | 0.5 |
| Headroom (m) | | 1.53 |
| Cabin Width (m) | 1.96 | 1.98 |
| Seat Width (m) | | 0.58 |
| Seat Height (m) | | 1.66 |
| Cabin Diameter (m) | 1.96 | 1.98 |
| Fuselage Outer Diameter (m) | | 2.06 |
| Fuselage Wall Thickness (m) | | 0.04 |

*Table 5.1: Typical Business Jet Cabin Cross Section*

### 5.1.3. Exits and Emergency Exits

According to FAR 25.807:

*For a passenger seating configuration of 1 to 9 seats, there must be at least one Type IV or larger overwing exit in each side of the fuselage or, if overwing exits are not provided, at least one exit in each side that meets the minimum dimensions of a Type III exit.*

For this design, a Type I exit was chosen as the main exit of the aircraft, located on the forward portion of the left side of the fuselage. This exit must be equipped with stairs to allow easy loading of passengers from the ground which is standard on nearly all business jets. A Type I exit is a floor-level exit with a rectangular opening of not less than 24 inches wide by 48 inches high, with corner radii not greater than 8in (1.22m x 0.61m). For this design, the door dimensions were made to be 50in x 26in (1.27 m x .66m) with corner radii of 8in to allow slightly more room for passengers to enter and exit the aircraft.

A second, emergency exit of Type IV or larger is also required under FAA regulations. A Type IV exit is defined as a rectangular opening of not less than 19in wide by 26in high, with corner radii not greater than 6.3in, located over the wing (0.48m x 0.66m). An exit of these dimensions was placed in the aft part of the fuselage on the right side over the wing. The sizing and placement of these two exits meets industry standards.

### 5.1.4. Cabin Floor Plan

The aircraft is designed to carry 8 passengers. In order to maximize space, there are 3 rows each with 2 seats to accommodate a total of 6 passengers in the main part of the cabin. These 6 seats are colored in blue in figure 5.3 below. The main cabin seats have a seat pitch of 1.8m which provides adequate legroom for passengers. The other two passengers will sit on a couch located in the galley. The couch measures 1.2m long which provides plenty of room for 2 passengers, and this couch is colored in green in figure 5.3. In the rear of the cabin there is also a lavatory which comes standard on almost all business jets. This lavatory measures 0.6m long, and the cabin totals 7m long.

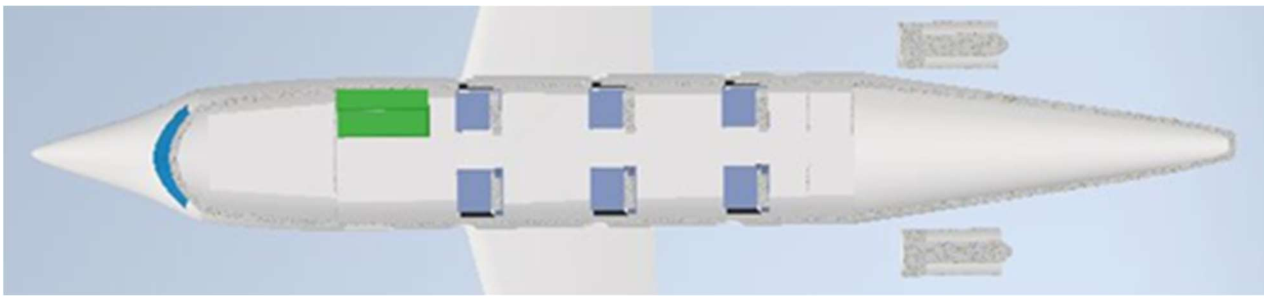

*Figure 5.3: Top View of Cabin Cross Section (Not to scale)*

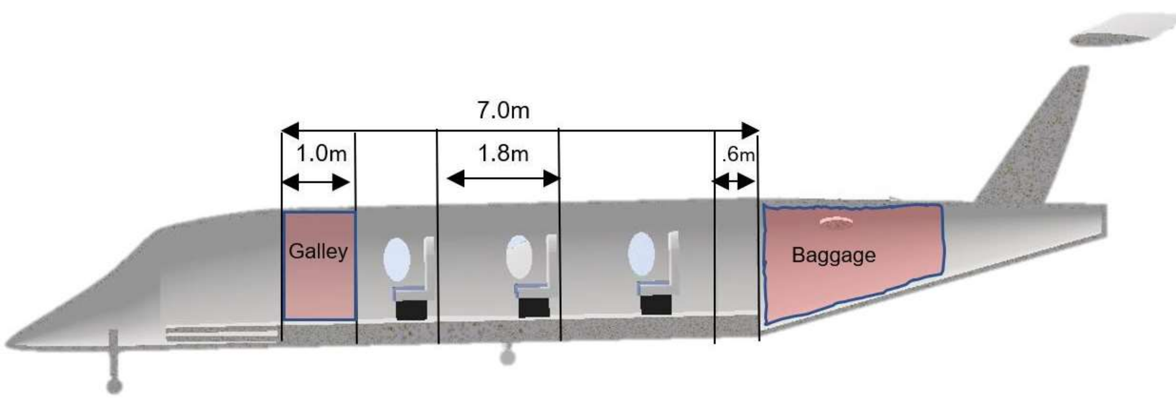


*Figure 5.4: Side View of Cabin Cross Section (Not to scale)*

Figure 5.4 provides a dimensioned side view of the cabin cross section with the main dimensions mentioned previously. A scaled detailed drawing of this view is provided in Appendix 4.2.

### 5.1.5. Design Flexibility

In order to show the flexibility of the cabin design, two separate top views are displayed. The first view in figure 5.5 shows the two front cabin seats reversed to look towards the rear of the cabin. This payload configuration allows placement of tables between the first 4 cabin seats, which can allow people to conduct business meetings during flight. The second configuration in figure 5.6

shows the easy removal of the couch in the galley. This configuration will only seat 6 passengers, but it will allow the passengers and crew to store extra luggage in the galley if needed, or it can simply be used to reduce the weight of the aircraft.

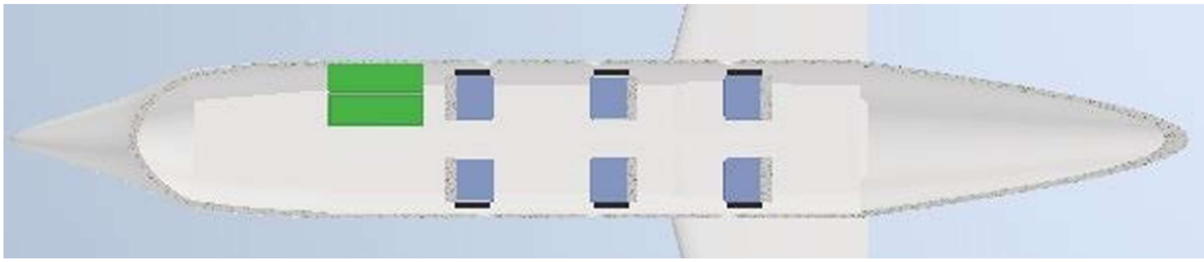

*Figure 5.5: Top View of Possible Cabin Configuration 1 (Not to scale)*

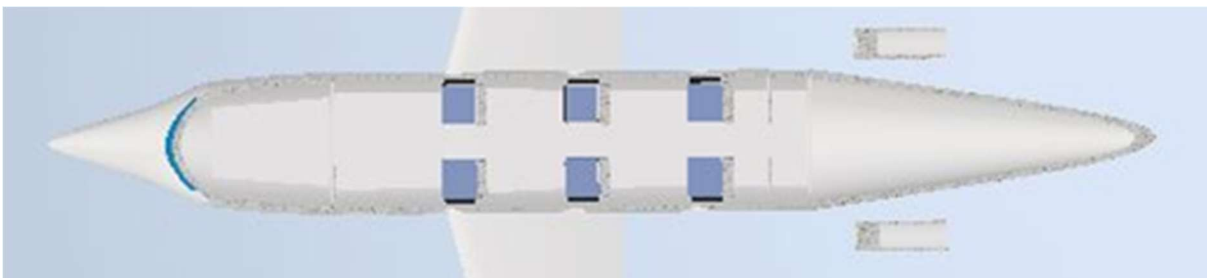

*Figure 5.6: Top View of Possible Cabin Configuration 2 (Not to scale)*

## 5.2. Cockpit/Nose Design

The cockpit design was also developed using an inside-out approach. In order to design an adequate cockpit, there is a compromise between anthropometrics, pilot visibility, and aerodynamics.

### 5.2.1. Pilot Visibility Angles

The cockpit must be designed around the pilot's eye as the main point of reference to ensure safe operation and maneuvering of the aircraft. Based on anthropometric data, the eye of the pilot typically sits 47in, or 1.19m, from the nose bulkhead and 44in, or 1.12m, from the floor. Using this point of reference, the main visibility angles, such as the over nose, grazing, upward, and overside angles could be determined. Below is a summary of the visibility angles on the aircraft with comparisons to typical acceptable values in table 5.2. Figure 5.7 depicts the meaning of each of these angles in terms of pilot visibility.

| Pilot Visibility Angles | Our Aircraft | Acceptable Values |
|---|---|---|
| Over nose | 11 | 11-20 |
| Transparency/Grazing | 32 | > 30 |
| Upward | 19 | ≈ 20 |
| Overside | 35 | 35 |

*Table 5.2: Aircraft Visibility Angles Data*

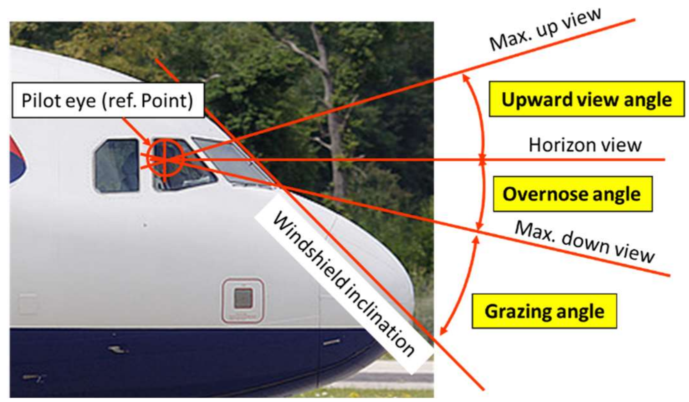


*Figure 5.7: Illustration of Visibility Angles*

### 5.2.2. Nose Length

The length of the nose is determined based on the nose fineness ratio, which is equal to the length of the nose divided by the largest diameter of the fuselage ($L_{Nose}$ / d). For a business jet, this value lies between 1.2-2.5, so a value of 2 was chosen for the nose fineness ratio. At this point, the diameter of the fuselage is known to be 2.06m. By using the previous equation, the length of the nose is found to be $L_{Nose}$ = 2.06*2 = 4.12m. This value was then compared to the necessary flight deck length to determine its feasibility. For an aircraft with 2 crew members, the overall length of the flight deck is 2.5m, computed from the nose pressure bulkhead to the rear door. The flight deck length is less than the total nose length, so the design is acceptable.

## 5.3. Tail Design

In similar fashion to the nose of the aircraft, the tail was designed with certain fineness ratios and angle requirements in mind. According to the PowerPoint slides, business jets usually have a tail fineness ratio of 2.5-5, defined by the ration of the tail length to the maximum fuselage diameter ($L_{Tail}$ / d). Like before, the fuselage diameter is known to be 2.06m, and assuming a tail fineness of 2.5, the length of the tail cone is found to be $L_{Tail}$ = 2.06*2.5 = 5.15m.

The two main angle requirements for the tail cone are the divergence angle and the rotation angle. The rotation angle must be at least 14 degrees to ensure that the tail does not strike the ground during take-off. For this aircraft, the rotation angle was made to be 18 degrees, based on the current landing gear configuration providing enough clearance for the tail. Also, the divergence angle must be ≤ 24 degrees for aerodynamic purposes. The aircraft was designed with a divergence angle of 17 degrees.

For business jets, there is no cargo space under the floor as in commercial airliners, so luggage will be stored in the tail section of the fuselage, assuming a luggage compartment volume of 4m$^3$. Also, two jet engines will need to be mounted to the tail section since this was the type of propulsion system decided upon in the conceptual design phase. However, at this point, the sizing of the engines and pylons are not known which is why a smaller fineness was chosen in case it must be slightly increased further into the design process.

## 5.4. Landing Gear Design

Similar to most business jets, a tricycle landing gear configuration will be used. The nose gear will be placed under the cockpit of the aircraft, and the main gear will be placed under the wings. Since business jets require loading of passengers from the ground level, shorter landing gear will be required. The main gear will retract into the wings, and the nose gear will retract under the cockpit. At this point in the design process, the exact size and positioning of the landing gear are not known, which may affect the current value for the rotation angle later. Current positioning of the gear can be seen in technical drawings in appendix 4.

## 5.5. Tail Plane and Wings

There is not much available data on the wing root chord length for typical business jets. Therefore, this value was assumed to be 1.9m with a wing sweep angle of about 15 degrees, and the validity of this assumption will be examined later in the design process. Finally, the tail span was assumed to be 6m based on the dimensions of similar aircraft found in the aircraft data collection in appendix 2.

## Sources and References:

**Reference Aircraft Data Sources:**
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https://www.aopa.org/-/media/Files/AOPA/Home/News/All-News/2010/Phenom-300-debut/Embraer_Phenom_300_Specsheet.pdf
https://www.globalair.com/aircraft-for-sale/Specifications?specid=1120
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https://en.wikipedia.org/wiki/Learjet_70/75
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**Lecture Notes:**
Course AESP 415-001 Aircraft Design 1

**Files:**
AESP415_001_Fall2020_02-TheDesignProcess_V1.pptx
AESP415_001_Fall2020_03-RequirementsAnalysis_V1.pptx
AESP415_001_Fall2020_04-ConceptualConfigurationDesign_V1.pptx
AESP415_001_Fall2020_05-FuselageDesign1_V1.pptx
AESP415_001_Fall2020_06-FuselageDesign2_V1.pptx

**Internet:**

Aircraft Images:
https://www.globalair.com/aircraft-for-sale/Specifications?specid=1120
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https://magellanjets.com/travel/citation-latitude-vs-citation-longitude/

Aircraft Regulations:
https://www.ecfr.gov/cgi-bin/text-idx?SID=f03fcd3f274d42c170731bb0f17aa17e&mc=true&node=se14.1.25_1807&rgn=div8
https://www.risingup.com/fars/info/part25-815-FAR.shtml

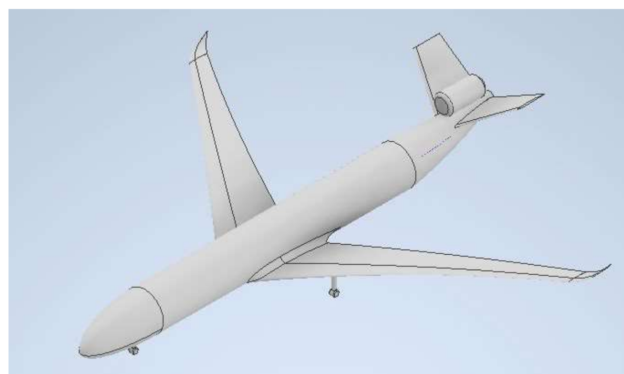
**Books:**
Aircraft Design: A Conceptual Approach
Daniel P. Raymer

# Appendices

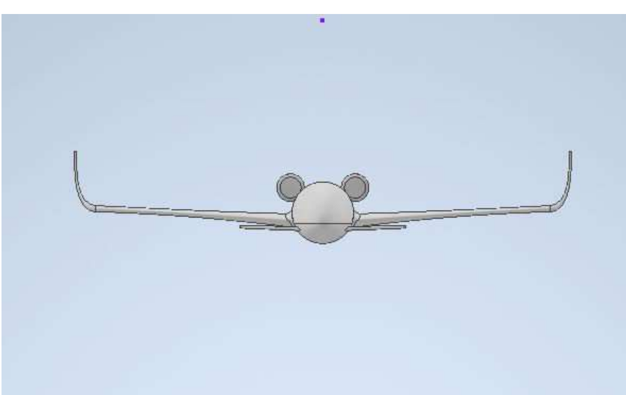
## Appendix 1: Conceptual Designs

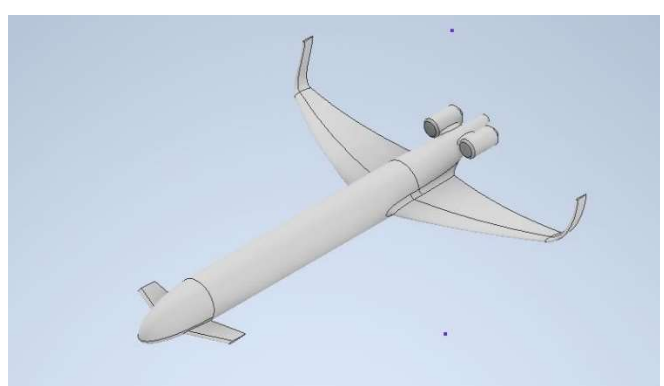
### Appendix 1.1. T-Tail Configuration

### Appendix 1.2. V-Tail Configuration



### Appendix 1.3. Unconventional Wing Tip Rudder Configuration





# Appendix 2: Aircraft Reference Data

| | | Occupancy | | Weight | | | | Performance | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Manufacturer | Type | Crew | Passengers | MTOW (kg) | BOW (kg) | Max Payload | Fuel (kg) | Range (km) | Cruise Speed (km/h) | Take-off Distance (m) | Landing Distance (m) | Operative Altitude (ft) |
| Cessna | Citation II | 2 | 8 | 6,849 | 3,923 | 1,066 | 2,254 | 3,700 | 746 | 1050 | 745 | 43,000 |
| Embraer | Phenom 300E | 2 | 10 | 8,150 | 5,344 | 1,196 | 2,428 | 3723 | 859 | 978 | 677 | 45,000 |
| Bombardier | Learjet 60 | 2 | 8 | 10,659 | 6700 | 1011 | 3588 | 4,463 | 840 | 1661 | 917 | 51,000 |
| Bombardier | Challenger 300 | 2 | 8 | 17622 | 10818 | 1,588 | 6418 | 5,646 | 850 | 1,466 | 792 | 45,000 |
| GulfStream | G100 | 2 | 7 | 11,181 | 6,515 | 1195 | 4248 | 5,462 | 896 | 1828 | 797 | 45,000 |
| Honda | HA-420 HondaJet | 2 | 7 | 4,854 | 3303 | 635 | 1290 | 2,661 | 782 | 1219 | 914 | 43,000 |
| Bombardier | Learjet 45 | 2 | 9 | 9,752 | 6,300 | 1002 | 2750 | 3,167 | 804 | 1644 | 750 | 51,000 |
| Pilatus | PC-24 | 2 | 8 | 8300 | 5316 | 1134 | 6974 | 3,334 | 815 | 893 | 724 | 45,000 |
| Eclipse | EA500 | 2 | 5 | 2,721 | 1,739 | 494 | 770 | 2,084 | 685 | 715 | 686 | 41,000 |
| Bombardier | Learjet 24 | 2 | 5 | 6,123 | 3552 | 1619 | 2553 | 2,728 | 774 | 1033 | 1008 | 45,000 |
| Cessna | Citation XLS+ | 2 | 12 | 9,163 | 5833 | 1016 | 3057 | 3,889 | 817 | 1085 | 969 | 45,000 |
| Hawker | 400XP | 2 | 9 | 7,394 | 4,983 | 914 | 2228 | 4,000 | 828 | 1,374 | 889 | 45,000 |
| Cirrus | Vision SF50 | 1 | 6 | 2722 | 1649 | 602 | 910 | 2,222 | 440 | 973 | 917 | 28,000 |
| Gulfstream | G280 | 2 | 10 | 17,962 | 10954 | 1837 | 6622 | 6,667 | 850 | 1448 | 829 | 45,000 |
| Lockheed | JetStar II | 2 | 9 | 20,185 | 11,566 | 907 | 8149 | 4,820 | 811 | 1600 | 1189 | 43,000 |
| Bombardier | Learjet 75 | 2 | 8 | 9,752 | 6,300 | 957 | 2750 | 3,780 | 827 | 1219 | 811 | 51,000 |
| Beechcraft | Starship | 2 | 6 | 6,759 | 4681 | 1034 | 1717 | 2,804 | 568 | 1247 | 802 | 41,000 |
| Beechcraft | Premier 1 | 1 | 7 | 5,670 | 3810 | 712 | 1665 | 2648 | 789 | 1156 | 968 | 41,000 |
| Adam Aircraft | A700 | 2 | 6 | 3,855 | 2495 | 885 | 1003 | 2,593 | 615 | 1036 | 823 | 41,000 |
| Cessna | Citation CJ4 | 2 | 10 | 7761 | 4663 | 1007 | 2644 | 4010 | 835 | 1039 | 896 | 45,000 |
| Cessna | Citation Latitude | 2 | 9 | 13971 | 8462 | 1258 | 5168 | 5000 | 826 | 1091 | 756 | 45000 |
| Embrarer | Legacy 450 | 2 | 9 | 16000 | 10400 | 1325 | 5839 | 5378 | 856 | 1191 | 637 | 45000 |

| | | **Powerplant** | | | | **Dimensions** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Manufacturer | Type | Engines | Engine Manufacturer | Engine Model | Static Thrust (kN) (ea) | Length (m) | Height (m) | Tail Span (m) | Wing Span (m) | Cabin Height (m) | Cabin Width (m) | Cabin Length (m) |
| Cessna | Citation II | 2 | PW | JT15D-4 | 11 | 14.4 | 5.8 | 5.8 | 15.9 | 1.43 | 1.46 | 5.23 |
| Embraer | Phenom 300E | 2 | PW | PW535E | 15.48 | 15.64 | 5.1 | 6 | 15.9 | 1.5 | 1.55 | 5.23 |
| Bombardier | Learjet 60 | 2 | PW | PW305A | 20.46 | 17.88 | 4.47 | | 13.34 | 1.75 | 1.8 | 5.38 |
| Bombardier | Challenger 300 | 2 | Honeywell | HTF 7000 | 30.4 | 20.92 | 6.2 | | 19.46 | 1.85 | 2.19 | 8.74 |
| GulfStream | G100 | 2 | Honeywell | TFE 731-40R | 18.9 | 16.94 | 5.54 | | 16.64 | 1.37 | 1.28 | 5.21 |
| Honda | HA-420 Honda Jet | 2 | GE Honda | HF120 | 9.1 | 12.99 | 4.54 | | 12.12 | 1.47 | 1.52 | 5.42 |
| Bombardier | Learjet 45 | 2 | Honeywell | TFE 731-20AR | 16.2 | 17.68 | 4.3 | | 14.58 | 1.5 | 1.55 | 6.02 |
| Pilatus | PC-24 | 2 | Williams Int. | FJ44-4A | 15 | 16.85 | 5.4 | 6.8 | 17 | 1.55 | 1.69 | 7.01 |
| Eclipse | EA500 | 2 | PW | PW610F | 4 | 10.1 | 3.4 | 4.11 | 11.4 | 1.28 | 1.43 | 3.75 |
| Bombardier | Learjet 24 | 2 | GE | CJ610-6 | 13.1 | 13.2 | 3.73 | | 10.87 | 1.34 | 1.49 | 2.74 |
| Cessna | Citation XLS+ | 2 | PW | PW545C | 18.32 | 16 | 5.2 | | 17.17 | 1.7 | 1.68 | 5.6 |
| Hawker | 400XP | 2 | PW | JT15D-5R | 14 | 14.76 | 4.24 | | 13.36 | 1.45 | 1.5 | 4.77 |
| Cirrus | Vision SF50 | 1 | Williams Int. | FJ33 | 8 | 9.36 | 3.32 | | 11.79 | 1.24 | 1.56 | 3.32 |
| Gulfstream | G280 | 2 | Honeywell | HTF7250G | 33.9 | 20.37 | 6.5 | | 19.2 | 1.85 | 2.11 | 7.87 |
| Lockheed | JetStar II | 4 | Honeywell | TFE731-3 | 16 | 18.41 | 6.22 | | 16.59 | 1.86 | 1.89 | 8.59 |
| Bombardier | Learjet 75 | 2 | Honeywell | TFE731-40BR | 17.1 | 17.7 | 4.31 | | 15.52 | 1.5 | 1.55 | 6.02 |
| Beechcraft | Starship | 2 | PW | PT6A-67A | 890 kW (Prop) | 14.05 | 3.94 | | 16.6 | 1.62 | 1.68 | 6.43 |
| Beechcraft | Premier 1 | 2 | Williams Int. | FJ44-2A | 10.23 | 14.02 | 4.67 | | 13.56 | 1.65 | 1.68 | 4.11 |
| Adam Aircraft | A700 | 2 | Williams Int. | FJ-33-4 | 6 | 12.42 | 2.92 | | 13.41 | 1.28 | 1.37 | 3.63 |
| Cessna | Citation CJ4 | 2 | Williams Int. | FJ44-4A | 16.11 | 16.26 | 4.69 | | 15.49 | 1.4 | 1.47 | 5.3 |
| Cessna | Citation Latitude | 2 | PW | PW306D1 | 26.28 | 19 | 6.4 | | 22.05 | 1.8 | 1.96 | 6.6 |
| Embraer | Legacy 450 | 2 | Honeywell | HTF7500E | 29.09 | 19.68 | 6.43 | 7.34 | 20.25 | 1.83 | 2.08 | 7.31 |

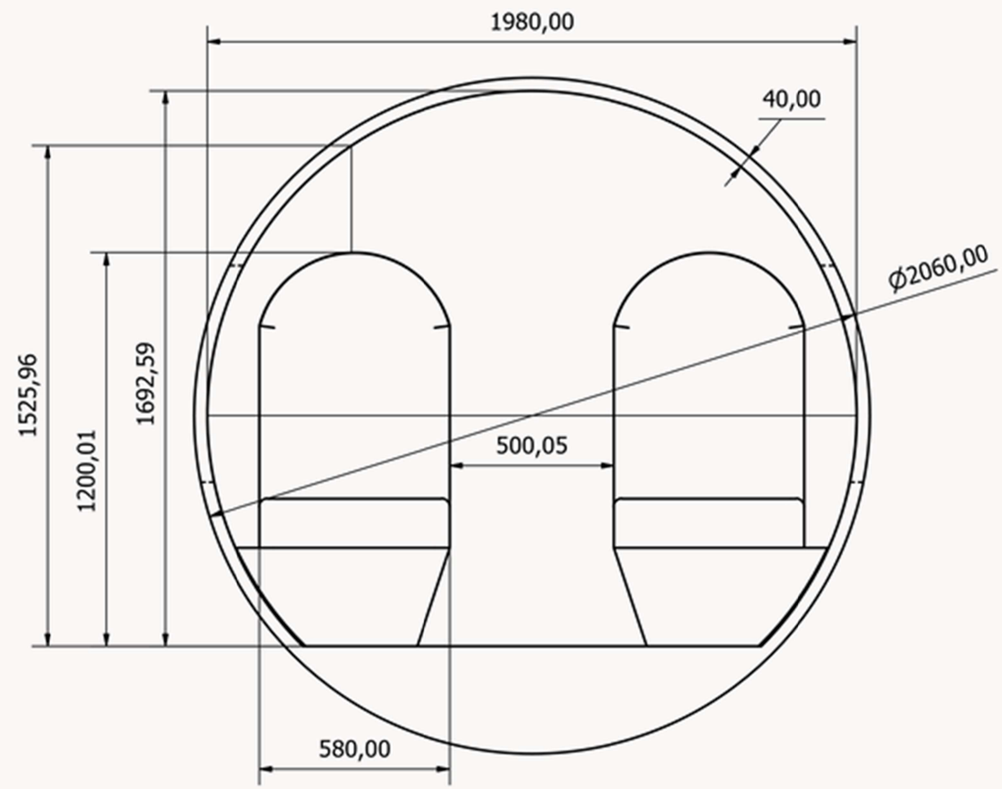
## Appendix 3: Aircraft parameters table

| Symbol | Parameters/Characteristic | Value | Unit |
|---|---|---|---|
| | | | |
| | ***Aircraft Wing Geometry*** | | |
| b | Wingspan | 16 | m |
| S | Wing area | | m |
| A | Aspect ratio | | |
| $\Lambda$ | Wing sweep angle | 15 | Degrees |
| | | | |
| | ***Cabin Characteristics*** | | |
| | Cabin Length | 7.0 | m |
| | Flight Deck Length | 2.5 | m |
| | Tail Cone Length | 5.15 | m |
| | Nose Cone Length | 4.12 | m |
| | Cabin Height | 1.7 | m |
| | Cabin Width | 1.98 | m |
| | Aisle Width | 0.5 | m |
| | Wall Thickness | 0.04 | m |
| | Fineness | 7.89 | - |
| | Nose Fineness | 2.0 | - |
| | Tail Fineness | 2.5 | - |
| | Chair Width | 0.58 | m |
| | Chair Pitch | 1.8 | m |
| | Overnose Angle | 11 | Degrees |
| | Overside Angle | 35 | Degrees |
| | Grazing Angle | 32 | Degrees |
| | Upward Angle | 19 | Degrees |
| | Divergence Angle | 17 | Degrees |
| | | | |
| | ***Weights and Loading*** | | |
| $W_E$ | Empty weight | | kg |
| $W_{MTO}$ | Maximum take-off weight | | kg |
| W/S | (maximum) Wing loading | | |
| | | | |
| | ***Performance Parameters*** | | |
| $h_{cruise}$ | Cruise altitude | 13,716 | m |
| $V_{cruise}$ | Cruise speed | 800 | km/h |
| $C_{Lcruise}$ | Cruise lift coefficient | | |
| $C_{Lmax}$ | Maximum lift coefficient (take-off) | | |
| $s_{TO}$ | Take-off distance | 1600 | m |
| $s_L$ | Landing distance | 900 | m |
| | Range | 4000 | m |

## Appendix 4: Aircraft Technical Drawings

The following appendices contain technical drawings of the aircraft done in Autodesk Inventor 2020. Each appendix is located on the following, respective pages.

**Appendix 4.1. Fuselage Front Cross Section**
**Appendix 4.2. Fuselage Side Cross Section**
**Appendix 4.3. Aircraft Front View**
**Appendix 4.4. Aircraft Side View**
**Appendix 4.5. Aircraft Top View**

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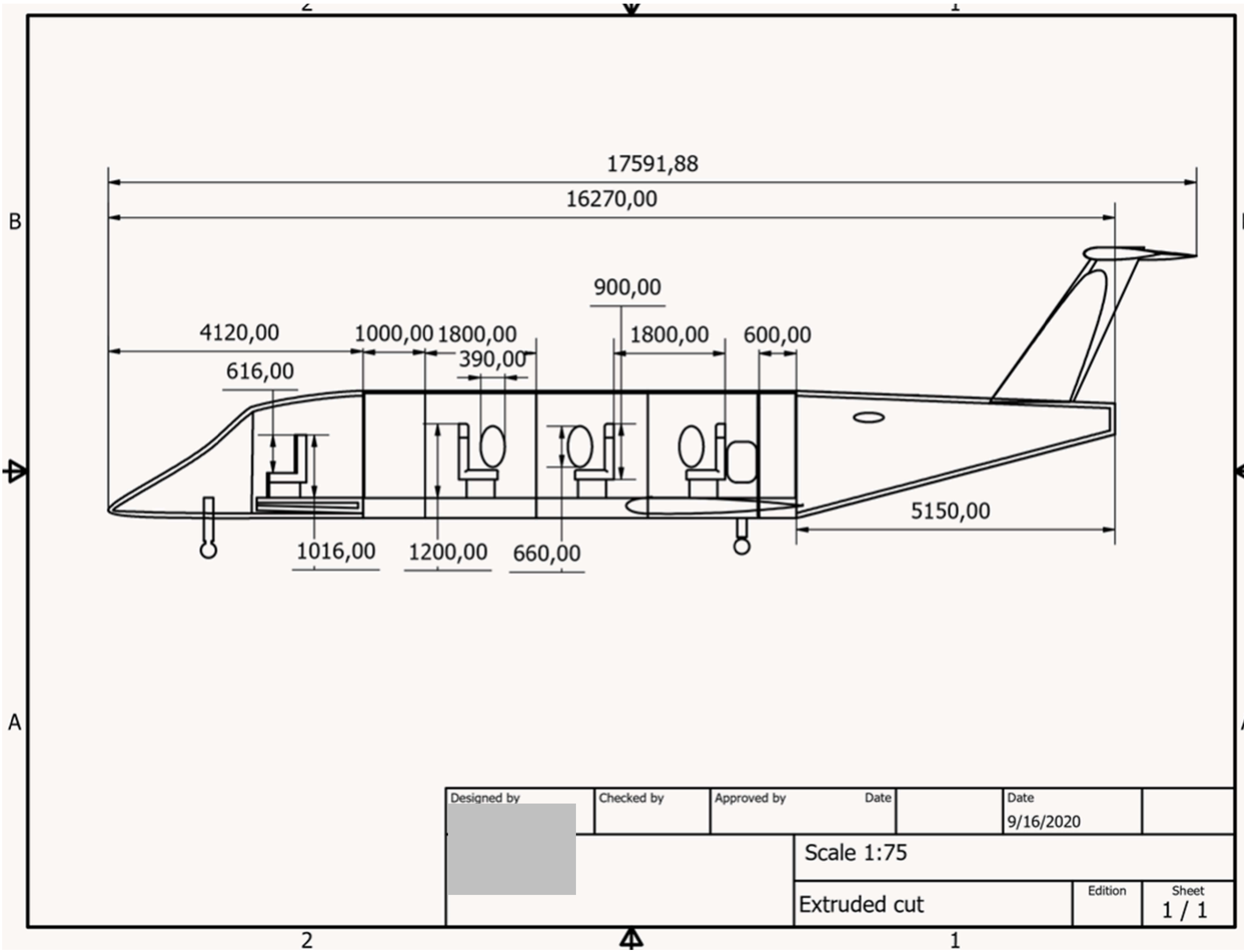
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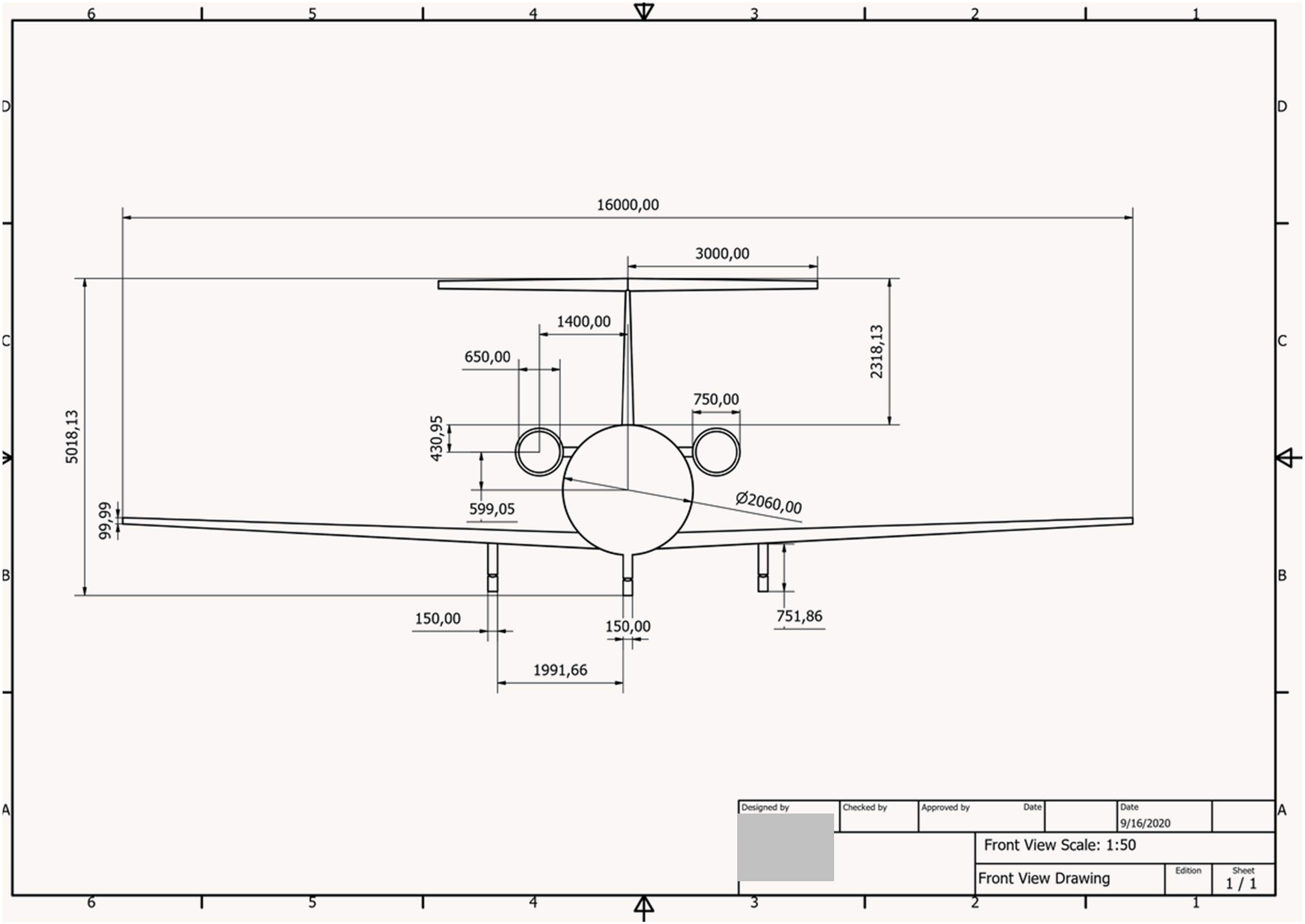
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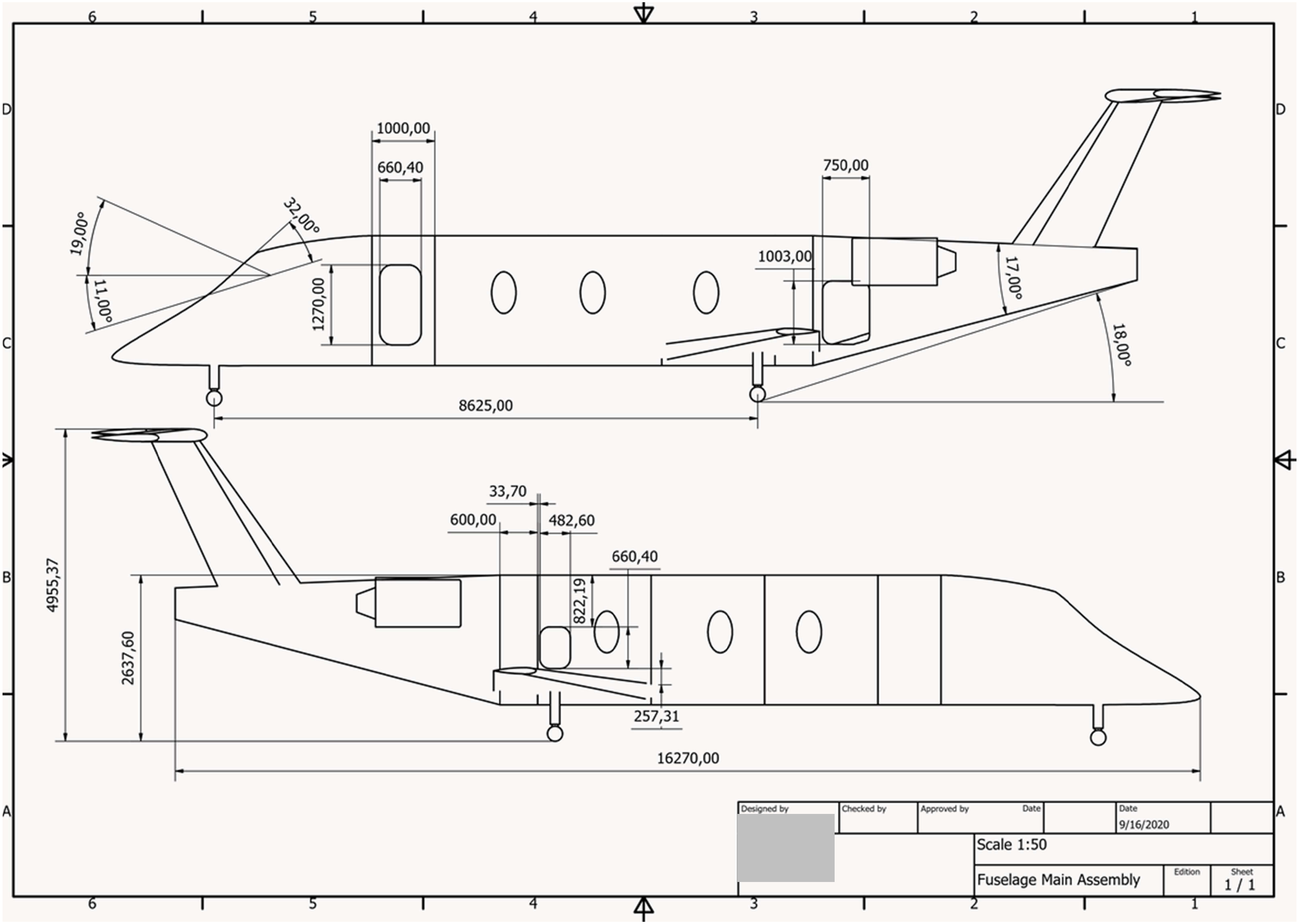
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Scale 1:50
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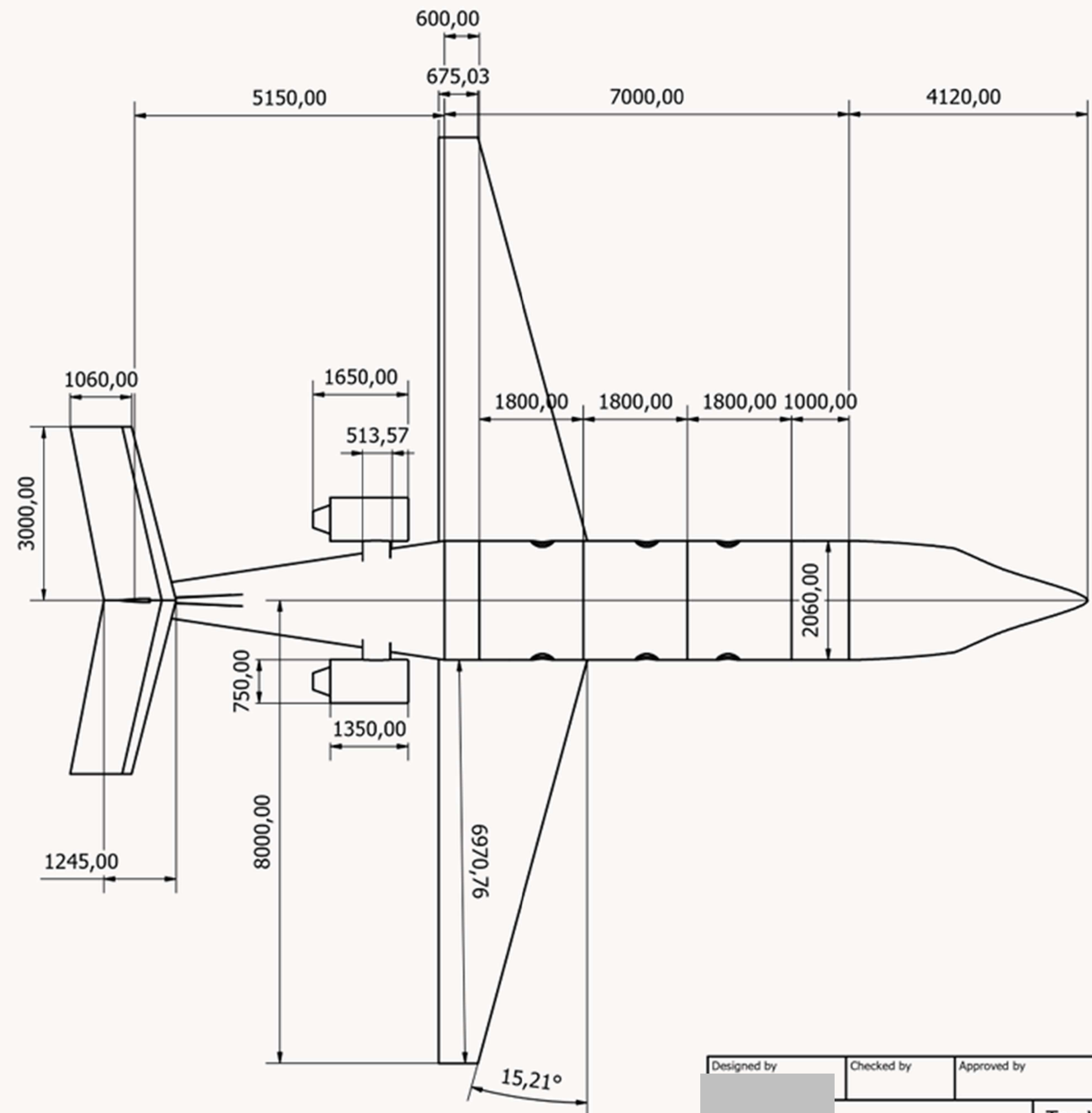


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