Design Proposal for Light Business Jet Family

STRATOKIWI AND STRATODODO

prepared in response to the AIAA 2016-2017 Graduate Team Aircraft Design Competition

TAS Aero 2016-2017

Institut Supérieur de l'Aéronautique et de l'Espace

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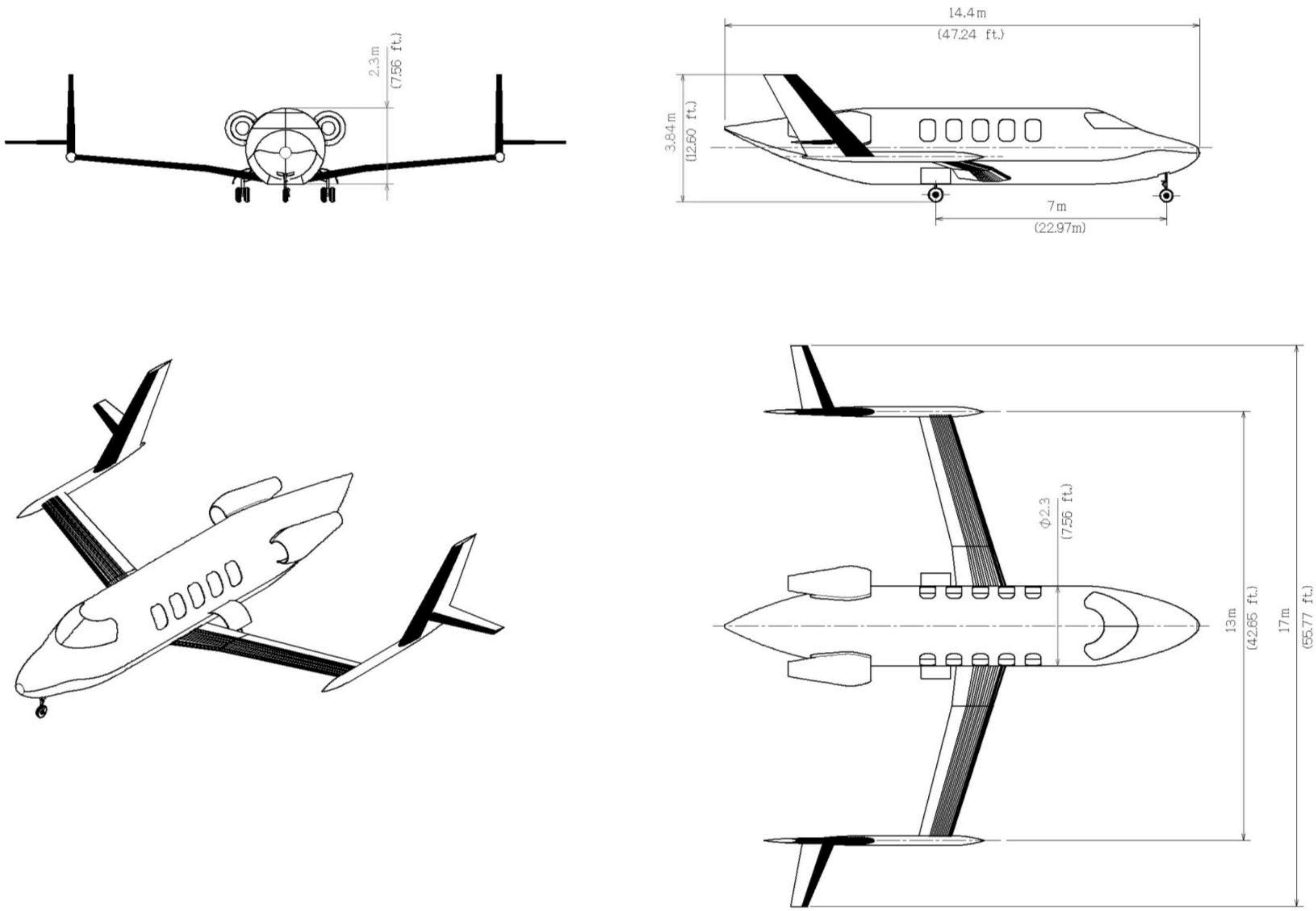
Executive Summary

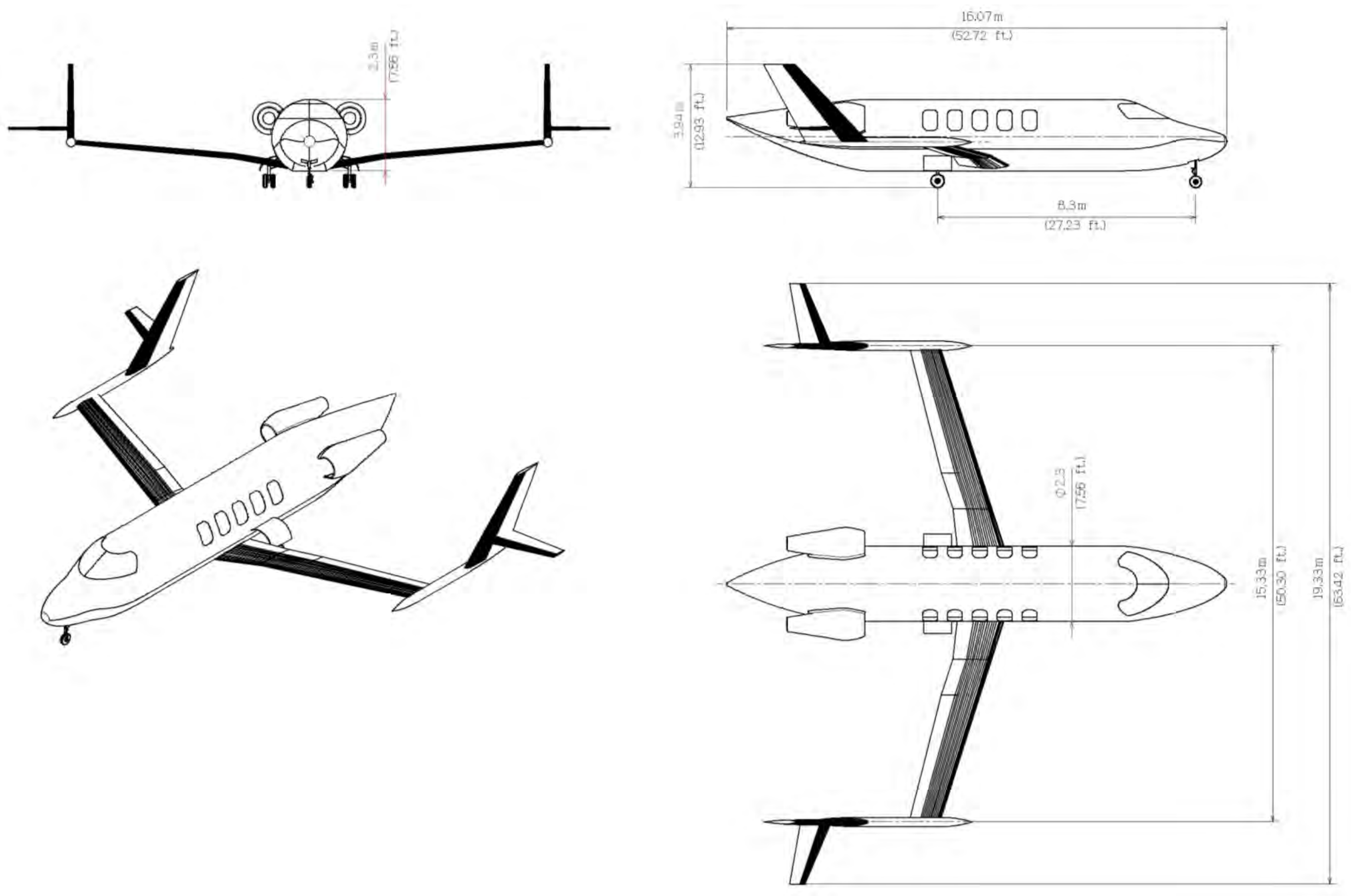
In early 2017, AIAA presented an RFP for two-member family long-range light business jet. In respond to this RFP, we, the Flapping Moustache team, proposed our designs: StratoKiwi and StratoDodo. StratoKiwi and StratoDodo are business jets designed with OHVS (outboard horizontal and vertical stabilizer) configuration with twin embedded engine at its aft fuselage. OHVS configuration was implemented mainly due to its claimed improvement to the overall aerodynamic efficiency of the aircraft. However, several complications and design challenge also arose and must be solved as the result of using this configurations. After numerous design iterations, the design of StratoKiwi and StratoDodo were finally refined and proven to be able to satisfy the requirements given by the RFP.

Compliance Matrix for StratoKiwi and StratoDodo

	RFP		Proposed Design		Related Section
	6-seater	8-seater	StratoKiwi	StratoDodo	
Certification	FAR 23	FAR 25	FAR 23	FAR 25	-
Expected Entry into Service (EIS)	2020	2022	2020	2022	-
Number of Crew	1 or 2	2	1 or 2	2	8.2
Number of Passenger	up to 6	up to 8	6	8	4.5 and 8.1
Baggage Capacity	227 kg (500 lbs)	454 kg (1000 lbs)	227 kg (500 lbs)	454 kg (1000 lbs)	4.3 and 4.5
Take-Off Balance Field Length at MTOW with Dry Pavement at Sea Level ISA conditions	1219 m (4000 ft)		648 m (2126 ft)	900 m (2953 ft)	5.5.1
Maximum Landing Field Length at MLW	1097 m (3600 ft)		561 m (1840 ft)	610 m (2001 ft)	5.5.2
Rate of Climb in Clean Configuration with Maximum Take-Off Power at Sea Level ISA Condition	1067 m/min (3500 ft/min)		1775 m/min (5823 ft/min)	1344 m/min (4409 ft/min)	5.3
High Speed Cruise Speed At 10670 m (35000 ft) Altitude	Mach 0.85		Mach 0.89	Mach 0.89	5.3
Optimum (Long-Range) Cruise Speed and Altitude	Mach 0.80 at 13720 m (Mach 0.80 at 45000 ft)		Mach 0.80 at 13720 m (45000 ft)	Mach 0.80 at 13720 m (45000 ft)	2.1 and 5.4.1
Maximum Cruise Range	4630 km (2500 nmi) (with 2 passengers)	4630 km (2500 nmi) (with 4 passengers)	4703 km (2539 nmi)	4701 km (2538 nmi)	5.4.2
Service Ceiling	15545 m (45000 ft)		17200 m (56430 ft)	15420 m (50500)	5.3



StratoKiwi – Three View Drawing



StratoDodo – Three View Drawing

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Nomenclature

AC	Aerodynamic Center
AIAA	American Institute of Aeronautics and Astronautics
AEO	All Engine Operating
ASD	Accelerate-to-Stop Distance
CG	Center of Gravity
CTOD	Continued Take-Off Distance
DRO	Design Requirements and Objectives
EIS	Entry into Service
FAR	Federal Aviation Regulations
HTP	Horizontal Tail Plane
LG	Landing Gear
MAC	Mean Aerodynamic Chord
MLW	Maximum Landing Weight
MTOW	Maximum Take-Off Weight
OEI	One Engine Inoperative
OHVS	Outboard Horizontal and Vertical Stabilizer
OHS	Outboard Horizontal Stabilizer
OVS	Outboard Vertical Stabilizer
RFP	Request for Proposal
VTP	Vertical Tail Plane

a	Speed of sound
$b_{0.5}$	Liftting surface’s half span
$C_{l,max}$	Airfoil's maximum lift coefficient
c_r	Lifting surface’s root chord length
c_t	Lifting surface’s tip chord length
g	Gravity acceleration
i_r	Lfting surface cross-section's incidence angle at root
i_t	Lfting surface cross-section's incidence angle at tip
LoD	Aerodynamic efficiency, lift-to-drag ratio
M	Mach number
M_{cr}	Cruise Mach number
R	Range
SFC	Specific Fuel Consumption
TW	Thrust-to-Weight Ratio
TW_{TO}	Take-Off Thrust-to-Weight Ratio
t/c	Thickness ratio in fraction of chord
V	Airspeed
WS	Wing loading
WS_{TO}	Take-Off Wing Loading

$\Lambda_{c/4}$	Lifting surface’s swept angle of 25% chord line
Γ	Lifting surface’s dihedral angle

1. INTRODUCTION

1.1. Background

As the theme for The American Institute of Aeronautics and Astronautics (AIAA)'s 2016-2017's graduate team design competition, a request for proposal (RFP) for light business jet aircraft family was presented. The RFP asked for two fixed-wing aircraft designs and as a response to this RFP, two light business aircraft designs, named StratoKiwi for the six-seater aircraft and StratoDodo for the bigger version eight-seater aircraft, will be presented in this proposal. This proposal was prepared by a group of six students who are currently enrolled in *TAS Aero program* and *TAS Aero – option Flight Test Engineering (FTE) program* at École nationale supérieure de l'aéronautique et de l'espace (ISAE-SUPAERO) in Toulouse, France.

While this project itself was not a part of any official curriculum activities of ISAE-SUPAERO, the competition drew out our attentions. Several students in the program who already had an interest in aircraft design were eager to participate. One of the faculty members of the program also stated that having a course on aircraft design project will be beneficial, however, he also admitted that he couldn't afford to fit in any aircraft design course in to the curriculum because the course itself is already tightly packed. Thus, in order to have some insight and practical learning in conceptual aircraft design, we, the Flapping Moustache team, was assembled in February 2017 to participate in this competition and proudly presents this design proposal.

1.2. Project Outline and Design Methodology

In order to accomplish this project, a workflow as shown in Figure 1-1 below was carried out. The project was started by evaluating given RFP and studying the existing competitor aircrafts. Since the RFP asked for both FAR-23 certified aircraft and FAR-25 certified aircraft, both of these regulations were also examined to find any constraining requirement that must be addressed early on. From given RFP, design requirements and objectives (DRO) were then formulated. Several requirements stated on given RFP were expanded in order to give StratoKiwi and StratoDodo some advantages over the existing competitors. On the other hand, several requirements that were not explicitly stated in the RFP were defined based on trade studies. The formulation of DRO is explained in detail in chapter 2.

With the DRO formulated, design process was started. Most references, such as Nikolai[9], Roskam[13] and Raymer[11], suggest to start the design process by performing initial sizing to select the design points. This includes initial weight estimation and matching chart generation. Dassault technical manual, however, suggests to start from the cabin interior design as cabin interior is considered as the most important part of business jet. Since both approaches doesn't seem to be conflicted with each other, both works were executed in parallel. At the same time, aircraft configuration study was also carried out to select the aircraft configuration for StratoKiwi and StratoDodo. The detail of initial sizing and configuration study are described in chapter 3 while the interior design is described in detail in chapter 8.

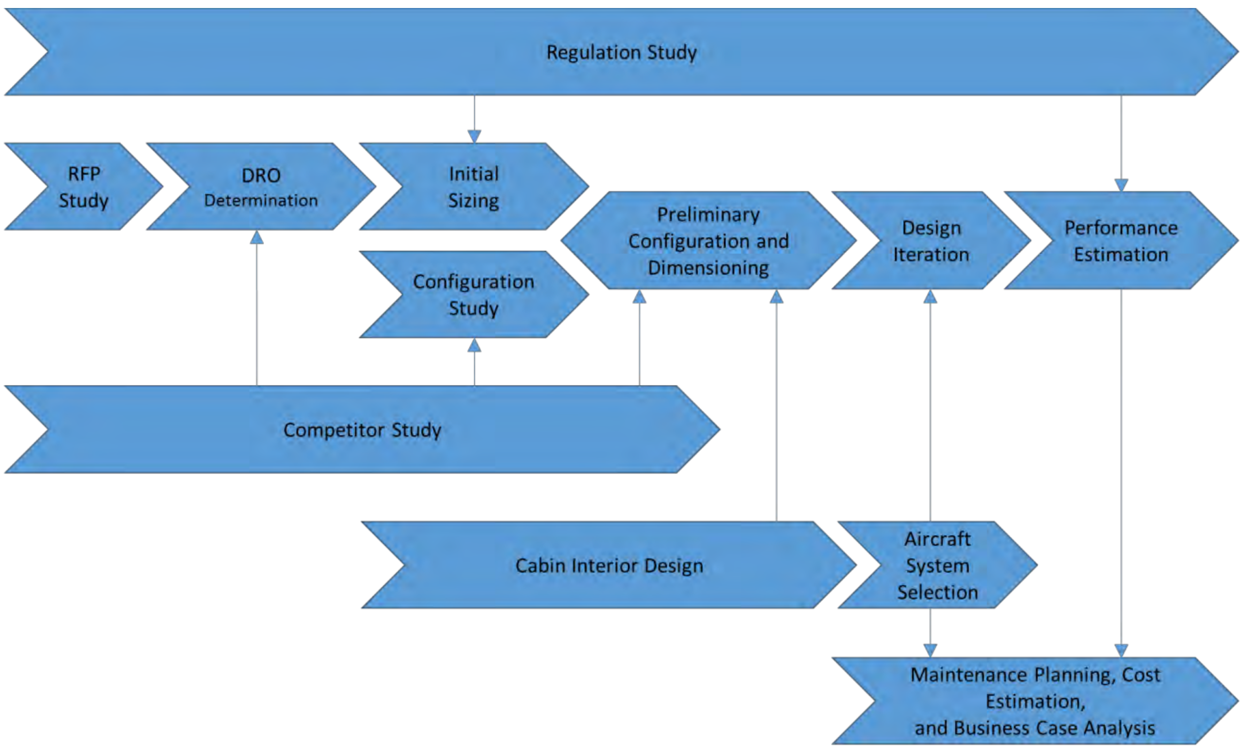


Figure 1-1: Project Workflow for the Design Development of StratoKiwi and StratoDodo

From the configuration study, OHVS (Outboard Horizontal and Vertical Tail) configuration was chosen and critical dimensions, such as wingspan and wing surface, were assigned and off-the-shell engine was selected based on the constraints imposed from the results of the initial sizing. Preliminary sizing on the parameters of other aircraft components were done individually to satisfy their own requirements, such as tail volume requirements for tail surface sizing, landing gear load distribution requirements for landing gear sizing, and so on. However, since the requirement of one aircraft component often contradicts with the requirement of other components, compromises between two or more parameters were necessary when integrating all the aircraft components. Design iteration was also done to ensure optimal compromise between all requirements. The detail of preliminary sizing of all major aircraft component and the final result of design iteration are outlined in chapter 4. Note that these iterations also took into account the internal arrangement of aircraft systems as it affect the aircraft's weight and balance. The selection of aircraft system, however, had minimum impact on the design iteration and thus its selection process is outlined separately in chapter 7.

After the final design iteration was reached and agreed upon, the design of StratoKiwi and StratoDodo were frozen and detailed analysis were conducted. Firstly, aerodynamic analysis was done to estimate the aircrafts' drag polar and its stability derivatives. This analysis is outlined in chapter 5. After that, structural analysis was done to ensure the structural integrity of the aircrafts as outlined in chapter 6. Ultimately, flight performance analysis was carried out to verify that StratoKiwi and StratoDowo can fulfill its DRO and this analysis is outlined in chapter 5. These results were then used to conduct life-cycle cost estimation that are outlined in chapter 9.

2. DESIGN REQUIREMENTS AND OBJECTIVES

The RFP poses 16 quantitative requirements and 4 qualitative objectives for both aircrafts. While most of these requirements are clear and concise, some are open-ended and must be resolved before proceeding with the initial sizing. Some of these requirements can also be expanded in order to provide StratoKiwi and StratoDodo advantages over its existing competitor. In this chapter, these requirements are addressed and discussed in order to formulate DRO for both StratoKiwi and StratoDodo.

2.1. Long Range Cruise Condition

The RFP requires both aircrafts to be able to achieve cruise range of 4630 km (2500 nmi) with additional 185 km (100 nmi) for cruise to alternate destination. This means that in ideal cruise condition (cruise Mach number and cruise altitude), both aircrafts must be able to achieve said range. The ideal cruising condition is not prescribed by the RFP as it is typically chosen by the designer in order to optimize their aircraft. However, in this early stage of design process, no data was available for StratoKiwi and StratoDodo, thus, the selection of cruise was done using typical performance charts and Breguet range equation shown below.

$$R = \frac{M_{cr} \times a \times LoD}{g \times SFC} ln \left(\frac{W_{initial}}{W_{final}} \right)$$

(2-1)

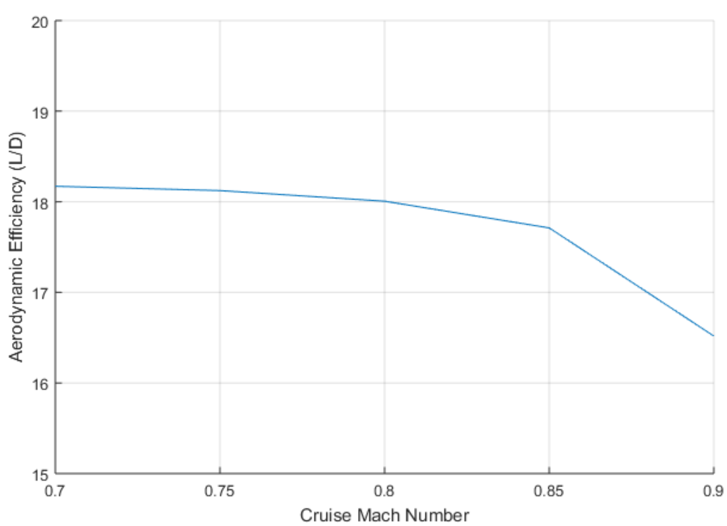


Figure 2-1: Aerodynamic Efficiency Estimation for 5670 kg Aircraft

To choose the optimal cruise Mach number and altitude, equation (2-1) was computed for several cruise Mach numbers and altitudes by dropping the weight ratio term as they represents the aircraft structure design whose value does not depend on cruise condition. The specific fuel consumption (SFC) value was computed based on typical performance of high bypass ratio turbofan at maximum thrust provided by Raymer[11] while the aerodynamic efficiency (LoD) was computed as a function of Mach number from class I drag polar estimation method provided by Roskam[13]. In drag polar estimation, aircraft mass was assumed to be 5670 kg (12500 lbs), which is the maximum allowable take-off mass for FAR 23 aircrafts. Figure 2-1 below shows the result of aerodynamic efficiency estimation while the following Figure 2-2 shows the resulting specific range achieved for various cruise condition.

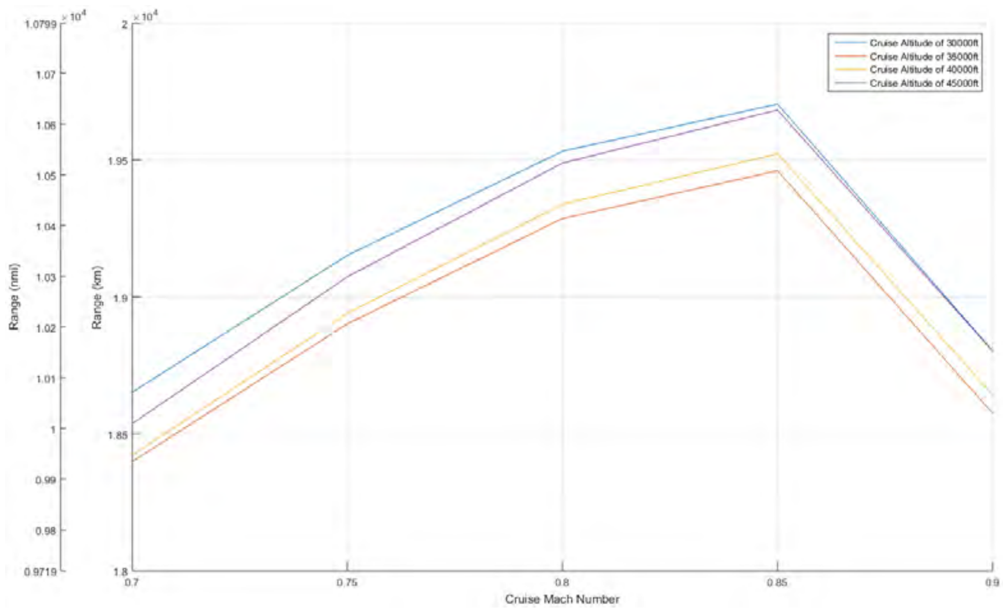


Figure 2-2: Range Estimation for Various Cruise Condition

Figure 2-2 above shows that the maximum range is achieved at cruise altitude of 30000 ft at Mach number of 0.85. However, cruise altitude of 45000 ft was preferred as it is above the airline traffic altitude while the reduction of range compared to cruise altitude of 30000 ft is insignificant. At 45000 ft, cruise Mach number of 0.85 was also deemed to be hard to be achieved with high bypass ratio turbofan. As the consequence, more conservative Mach 0.8 was chosen. As the consequence, optimal cruise condition for StratoKiwi and StratoDodo was selected to be at Mach number of 0.8 and altitude of 45000 ft.

2.2. Cruise Ceiling and Service Ceiling

The RFP requires both StratoKiwi and StratoDodo to have service ceiling of 45000 feet. However, with the selection of optimal cruise condition outlined in section 2.1, this requirement become irrelevant. Maximum cruise ceiling and new service ceiling should be agreed upon. For maximum cruise ceiling, no merit could be found in choosing higher altitude that the optimal cruise altitude as engine's fuel consumption increases dramatically. Thus, maximum cruise ceiling of 45000 ft was agreed upon. For service ceiling, typical light business jet has service ceiling up to 51000 ft, but this will impose very strict climb-of-rate requirement due to the available thrust at that altitude. It is also deemed to far from the maximum cruise ceiling. Ultimately, after a quick discussion, it was agreed to set the service ceiling requirement at 47000 ft.

2.3. Family Aircraft Concept and Airframe Commonality

The RFP requires StratoKiwi and StratoDodo to share at least 70% of airframe structure and aircraft system for the family concept. However, the RFP also states that StratoKiwi shall be certified under FAR 23 while StratoDodo under FAR 25. Since FAR 23 impose maximum allowable take-off weight of 5670 kg (12500 lbs), StratoKiwi's MTOW was guesstimated to be close to but be less than 5670 kg (12500 lbs) while StratoDodo's MTOW was guesstimated to be around 5670 kg (12500 lbs). On the other hand, StratoDodo's empty weight is aimed to be around 120% of StratoKiwi's. This additional empty weight was expected to come from additional fuselage and wing segment implemented for StratoDodo. Detailed information regarding this extension is outlined in section 4.1.

2.4. Formulation of DRO for StratoKiwi and StratoDodo

Based on given RFP and several concerns stated in the previous section, DRO for StratoKiwi and StratoDodo was then formulated and summarized in Table 2-1 below.

Table 2-1 : DRO for StratoKiwi and StratoDodo

	StratoKiwi	StratoDodo
Certification	FAR 23	FAR 25
Expected Entry into Service (EIS)	2020	2022
Number of Crew	1 or 2	2
Number of Passenger	up to 6	up to 8
Baggage Capacity	227 kg (500 lbs)	454 kg (1000 lbs)
Take-Off Balance Field Length (BFL) at MTOW with Dry Pavement at Sea Level ISA conditions	1219 m (4000 ft)	
Maximum Landing Field Length at MLW	1097 m (3600 ft)	
Rate of Climb in Clean Configuration with Maximum Take-Off Power at Sea Level ISA Condition	1067 m/min (3500 ft/min)	
Rate of Climb in Clean Configuration at Cruise Ceiling (13716 m / 45000 ft)	91.4 m/min (300 ft/min)	
Rate of Climb in Clean Configuration at Service Ceiling (14326 m / 47000 ft)	30.4 m/min (100 ft/min)	
High Speed Cruise Speed and Altitude	Mach 0.85 at 10670 m (Mach 0.85 at 35000 ft)	
Optimal (Long-Range) Cruise Speed and Altitude	Mach 0.80 at 13720 m (Mach 0.80 at 45000 ft)	
Maximum Cruise Range	4630 km (2500 nmi) (with 2 passengers)	4630 km (2500 nmi) (with 4 passengers)
Service Ceiling	14326 m (47000 ft)	
MTOW	less than 5670 kg (12500 lbs)	close to 5670 kg (12500 lbs)
Empty Weight	-	120% of StratoKiwi's
Shared Airframe Weight	70% of Airframe Weight	

3. INITIAL SIZING & SELECTION OF AIRCRAFT CONFIGURATION

From the formulation of DRO described in the previous chapter, design process of StratoKiwi and StratoDodo was started by performing initial sizing and choosing the aircraft configuration. Initial sizing consists of initial weight sizing, generation of matching chart, and selection of design points. In this chapter, the process of initial sizing and aircraft configuration selection are described briefly and the results of initial sizing and the selected aircraft configuration will be outlined.

3.1. Definition of Mission Profile

Since StratoKiwi and StratoDodo are business jets, its main purpose is to transport payload (in this case, passengers and cargo), its mission profile will consist of the standard take-off, climb, cruise, descent, and landing as shown by the blue lines (1-2-3-4-5-8-9) in Figure 3-1. However, to anticipate emergency scenario, and two additional mission segments (6 and 7), which are alternate cruise and loiter must be added to the mission profile. Alternate cruise segment was added to anticipate the need to divert to an alternative airport in case it is not possible to land at the destination airport. On the other hand, Loiter segment was added to anticipate the need to wait before landing due to traffic congestion around the airport. Alternate cruise range of 100 nmi was selected as required by the RFP while loiter time of 30 minutes was selected as suggested by Roskam[13].

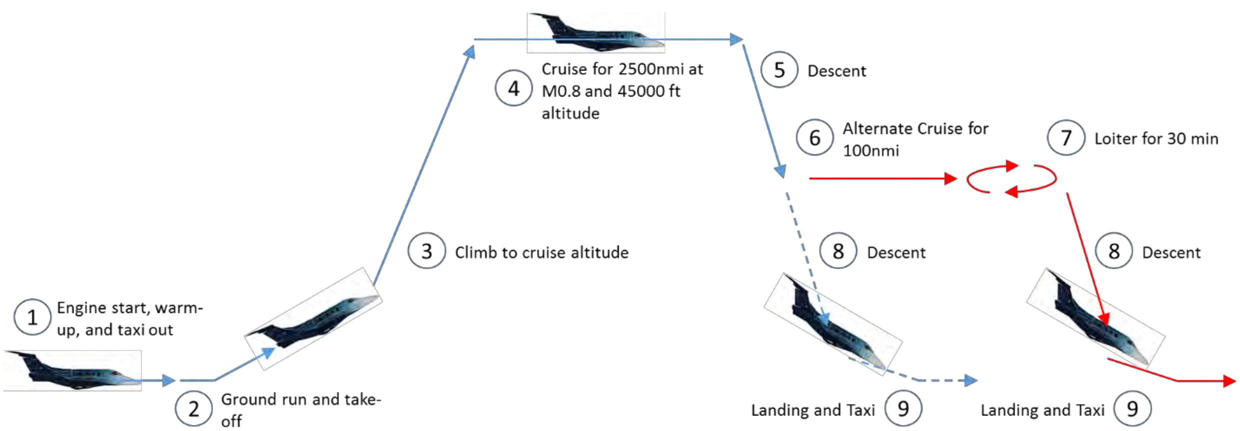


Figure 3-1: Mission Profile of StratoKiwi and StratoDodo

With the mission profile of StratoKiwi and StratoDodo defined as shown by Figure 3-1, aircraft weight fraction after a mission segment can be computer for all mission segments and then summed up to find the aircraft weight fraction after the mission. Weight fraction for cruise segment and loiter can be computed with Breguet range equation and endurance equation respectively while typical weight ratio values for other mission segments are readily available based on historical statistics in Nikolai[9], Roskam[13], and Raymer[11].

3.2. Initial Weight Sizing

In initial weight sizing, an aircraft's take-off weight, empty weight, and its mission fuel weight are estimated by fitting aircraft's weight fraction after a mission into the historical trends that relates an aircraft's take-off weight with its empty weight in a log-log relation for a certain aircraft classification. This can be easily done with a simple iterations and its step-by-step detail can be seen in Nikolai[9], Roskam[13], and Raymer[11]. Note that each references came up with their own historical weight trend and in this work, historical weight trend suggested by Roskam[13] was used.

While initial weight sizing procedure is pretty straightforward, it requires the aircrafts mission weight fraction whose value can't be computed without knowing the aircrafts aerodynamic efficiency and the engine SFC. Roskam[13] and Raymer[11] suggest typical value for these parameters that can be chosen as design objectives. However, selection must be done carefully. Selecting an optimistic value might put a huge burden on the next design process and may end up unachievable while selecting a pessimistic value might cause the aircraft to be unfeasible. Ultimately, a sensitivity study was done to determine the appropriate design objective for aerodynamic efficiency and engine SFC. This was done by performing initial weight sizing with various maximum aerodynamic efficiency values and optimal SFC values. In doing so, it was assumed that the aerodynamic efficiency at cruise, alternate cruise, and loiter segment are at 86%, 75%, and 100% of maximum aerodynamic efficiency value while the engine SFC at cruise, alternate cruise, and loiter segment are at 100%, 120%, and 150% of optimal engine SFC values.

The following Figure 3-2 and Figure 3-3 show the result of sensitivity study for StratoKiwi and StratoDodo. From these result, it was agreed to select maximum aerodynamic efficiency value of 13 and optimal engine SFC value of 0.65 as these parameters deemed reasonable to be achieved and it yielded weight estimation result that are close to existing competitor aircrafts. StratoKiwi was estimated to have an empty weight of 2075 kg (4574 lbs) and MTOW of 3782 kg (8337 lbs). This is similar to Morane Saulnier MS-760 that has maximum range of 1700 km (810 nmi). On the other hand, StratoDodo was estimated to have an empty weight of 4170 kg (9191 lbs) and MTOW of 7564 kg (16742 lbs). This is similar to Cessna Citation CJ4 that has maximum range of 4010 km (2165 nmi).

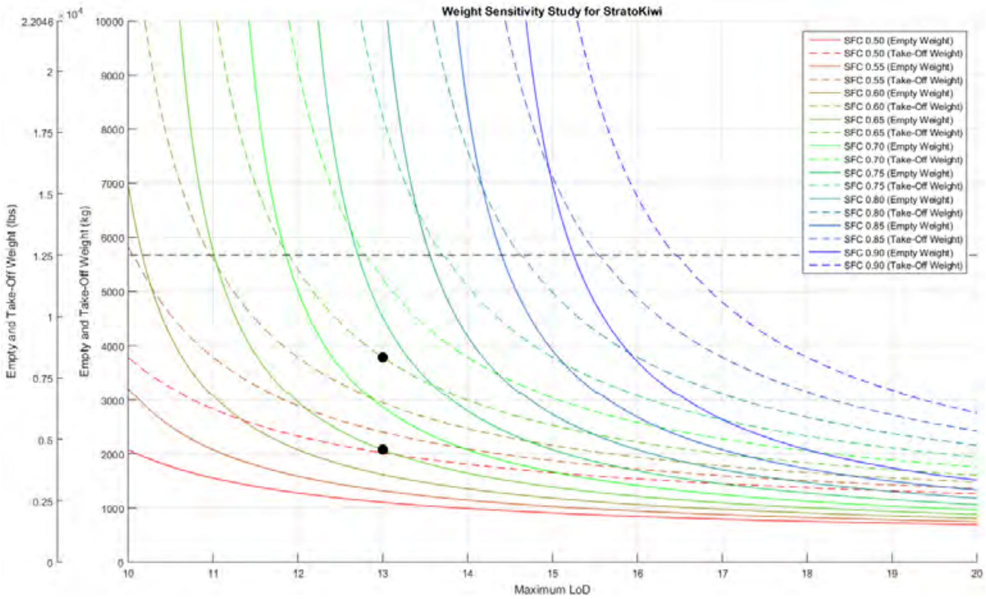


Figure 3-2: Weight Sensitivity Study for StratoKiwi

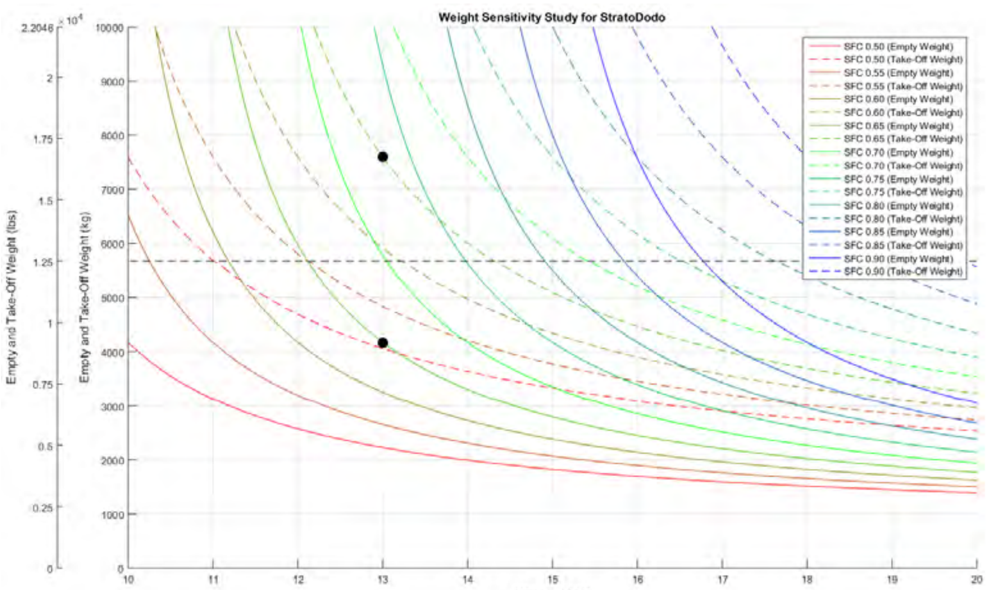


Figure 3-3: Weight Sensitivity Study for StratoDowo

Unfortunately, the weight estimation results show that StratoDodo's empty weight is almost twice of StratoKiwi's empty weight and this does not comply with the empty weight requirement stated in the DRO. StratoKiwi must be scaled up while StratoDodo must be scaled down so that their empty weights are within 30% of each other. This was done by plotting the historical weight trends provided by Roskam[13] with minimum take-off weight line that corresponds to mission weight fraction of StratoKiwi and StratoDodo respectively in a take-off weight versus empty weight plot as shown in Figure 3-4. Minimum take-off weight line corresponds to weight combinations provide enough fuel weight to complete the mission defined in section 3.1. StratoKiwi and StratoDodo, each has their own minimum take-off weight line and an appropriate weight combination should be chosen from this line for each aircraft while keeping their selection close with each other for the aircraft family commonality purpose. Ultimately, the scaled-up weight for StratoKiwi and the scaled-down weight for StratoDodo were selected to be as summarized in the following Table 3-1.

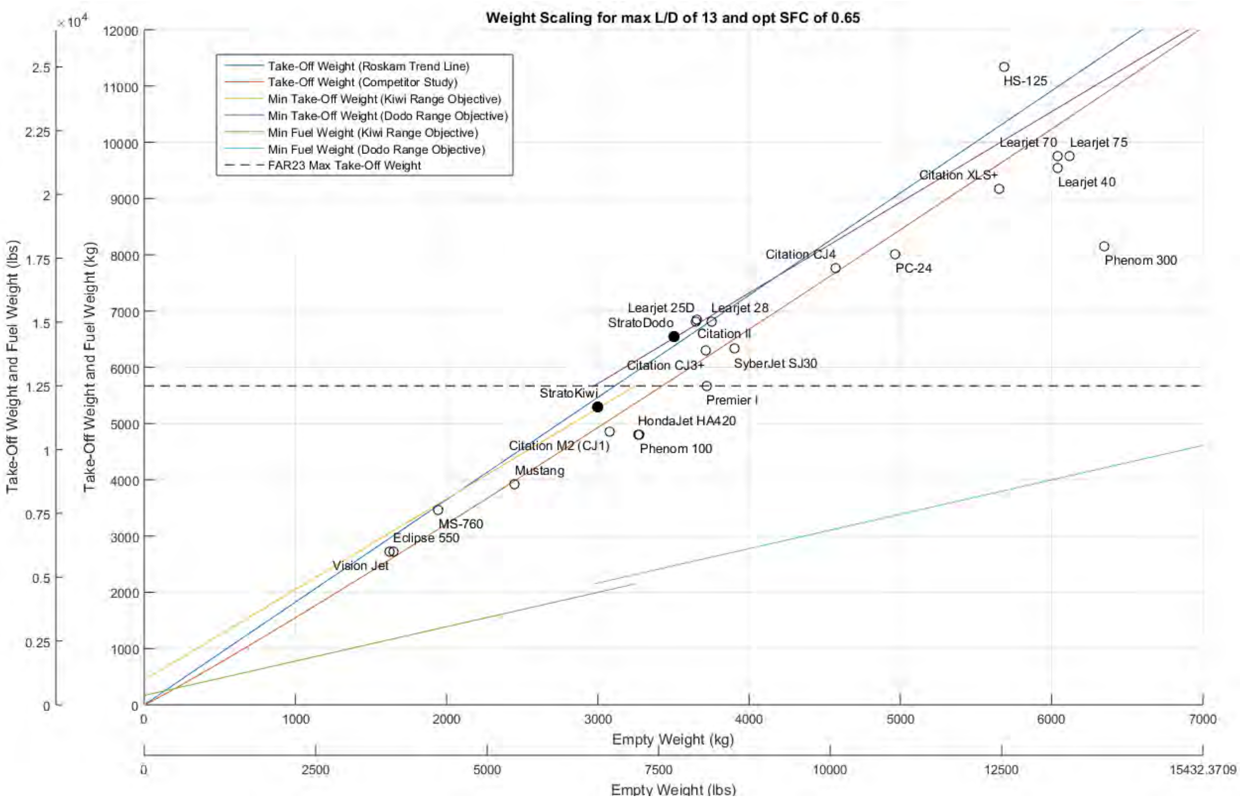


Figure 3-4: Weight Scaling Plot

Table 3-1: Initial Weight Sizing Results

	StratoKiwi	StratoDodo
Empty Weight	3000 kg (6613 lbs)	3500 kg (7716 lbs)
Mission Fuel Weight	2027 kg (4470 lbs)	2506 kg (5524 lbs)
Maximum Take-Off Weight	5300 kg (11685 lbs)	6550 kg (1440 lbs)

3.3. Matching Chart and Selection of Design Point

After initial weight sizing was done, two critical design parameters, take-off thrust-to-weight ratio (TW_{TO}) and take-off wing loading (WS_{TO}), must be selected. This is commonly referred as the selection of design point. Since these design points have a huge impact on aircraft performance, it should be selected by taking into account all performance requirements that must be achieved. This is done by creating matching chart and plotting each performance requirements as a curve (a function of T/W_{TO} and W/S_{TO}). With all performance requirements plotted as curves, feasible design region can be easily identified and the aircraft design point can be selected from these region.

To generate matching charts for StratoKiwi and StratoDodo, all performance requirements were identified and translated into curves of TW_{TO} versus WS_{TO}. In translating these performance requirements, class I drag polar estimation based on Roskam[13] were computed for both aircrafts and several additional design objectives were also determined. These drag polars and design objectives are summarized in the following Table 3-2 and Table 3-3. Note that the design objective values shown in Table 3-3 were determined based on the typical range of values suggested by Roskam[13]. Installed engine thrust ratios were also needed and it was estimated from William International FJ44-3E turbofan performance table provided by Nikolai[9]. To provide some design margin, it is also assumed that all performance requirements are to be satisfied with 90% of available thrust.

Table 3-2: Class I Drag Estimation for StratoKiwi and StratoDodo

	StratoKiwi	StratoDodo
Low Speed Drag Polar in Clean Configuration	$0.0182 + 0.0398{C_L}^2$	$0.0210 + 0.0332{C_L}^2$
Low Speed Drag Polar in Take-Off Configuration with Landing Gear Retracted	$0.0282 + 0.0424{C_L}^2$	$0.0410 + 0.0379{C_L}^2$
Low Speed Drag Polar in Take-Off Configuration with Landing Gear Extended	$0.0532 + 0.0424{C_L}^2$	$0.0660 + 0.0354{C_L}^2$
Low Speed Drag Polar in Landing Configuration with Landing Gear Retracted	$0.0932 + 0.0455{C_L}^2$	$0.0960 + 0.0379{C_L}^2$
Low Speed Drag Polar in Landing Configuration with Landing Gear Extended	$0.1182 + 0.0455{C_L}^2$	$0.1210 + 0.0379{C_L}^2$
High Speed Drag Polar in Clean Configuration	$0.0183 + 0.0398{C_L}^2$	$0.0211 + 0.0332{C_L}^2$

Table 3-3: Design Objectives for StratoKiwi and StratoDodo

	StratoKiwi	StratoDodo
Maximum Landing Weight	4000 kg	4500 kg
Maximum Lift Coefficient in Clean Configuration	1.6	1.6
Maximum Lift Coefficient in Take-Off Configuration	2.0	2.0
Maximum Lift Coefficient in Landing Configuration	2.2	2.2
Wing Aspect Ratio	10	12

Ultimately, matching charts for both aircrafts were generated and it is shown by the following Figure 3-5 and Figure 3-6. From this matching charts, the optimal take-off wing loading value that will yield minimum take-off thrust-to-weight ratio can be easily identified from the intersections between take-off distance sizing line and cruise sizing lines. This naturally led to the selection of design points shown in the following Table 3-4 (black dot in Figure 3-5 and Figure 3-6). Since StratoKiwi and StratoDodo's MTOW has been estimated previously in section 3.2, required take-off thrust and required wing surface were then determined directly from these design points and its values are also summarized in Table 3-4.

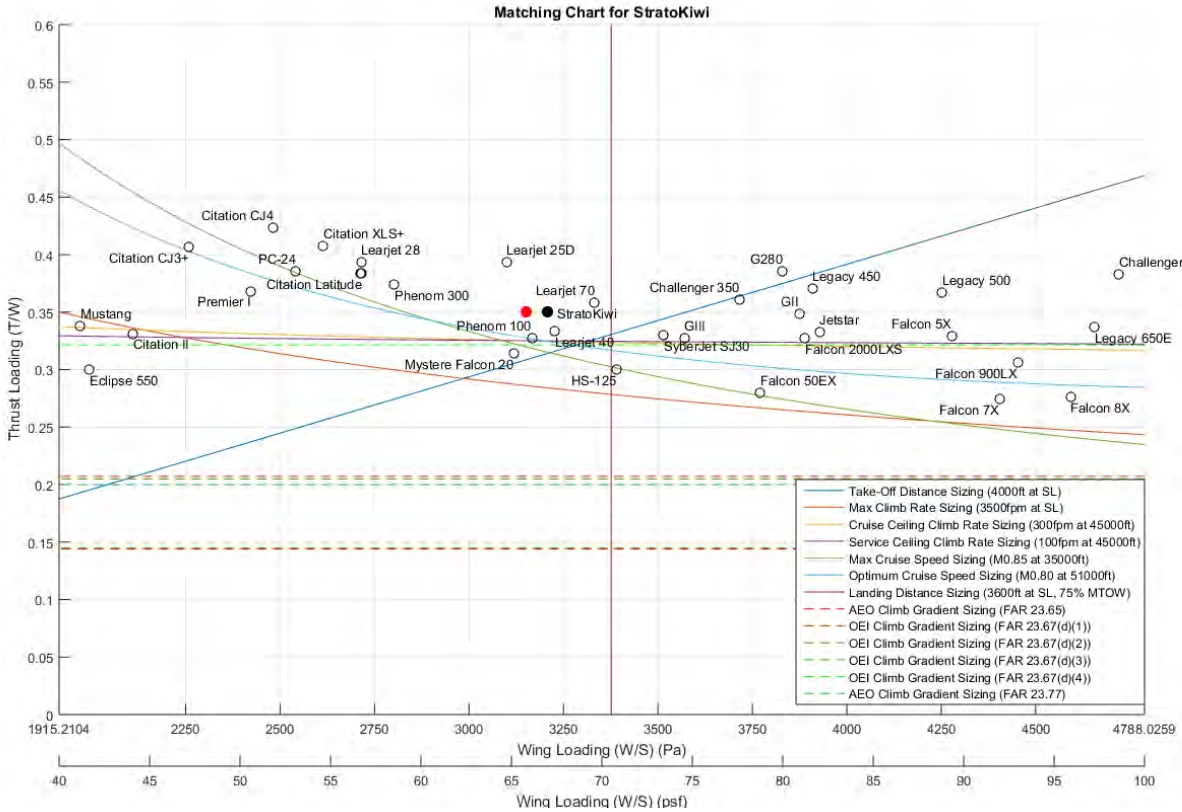


Figure 3-5: Matching Chart for StratoKiwi and its Design Point

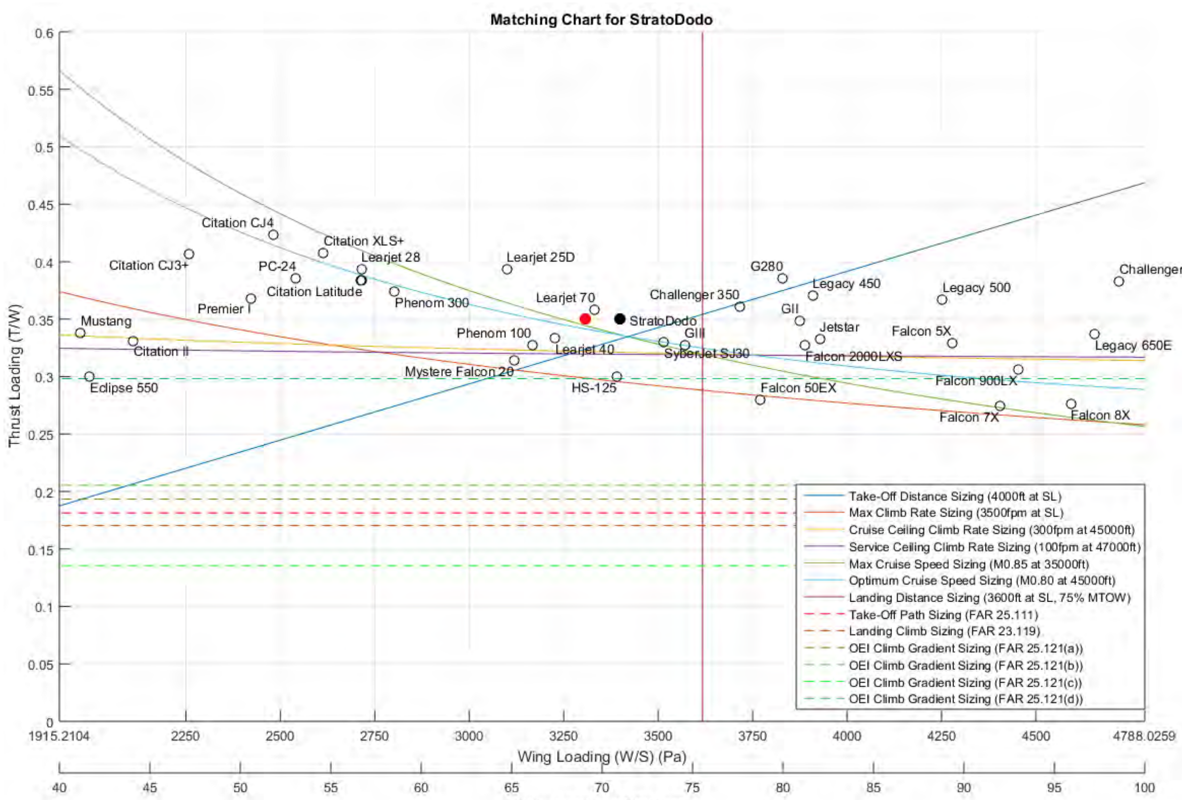


Figure 3-6: Matching Chart for StratoDodo and its Design Point

Table 3-4: Design Point Selections for StratoKiwi and StratoDodo

	Take-Off Thrust-to-Weight Ratio	Take-Off Wing Loading	Required Take-Off Thrust	Required Wing Surface Area
StratoKiwi	0.35	3208 Pa (67 psf)	18.19 kN (4089 lbs)	16.21 m^2 (174.48 ft^2)
StratoDodo	0.35	3300 Pa (71 psf)	22.59 kN (5054 lbs)	18.90 m^2 (203.44 ft^2)

While the design points had been selected, it is possible that these selected design points must be shifted as the design process continues. This is especially true for the wing surface area, as this design parameter is more likely needed to be shifted to accommodate other purposes such as fuel tanks. Since wing surface area will greatly affect aircraft's stall speed and maximum cruise speed, carpet plots were generated to see how far the wing surface area can be shifted from the design points if it is necessary. Figure 3-7 and Figure 3-8 below show the resulting carpet plot and the limit of increasing wing surface area.

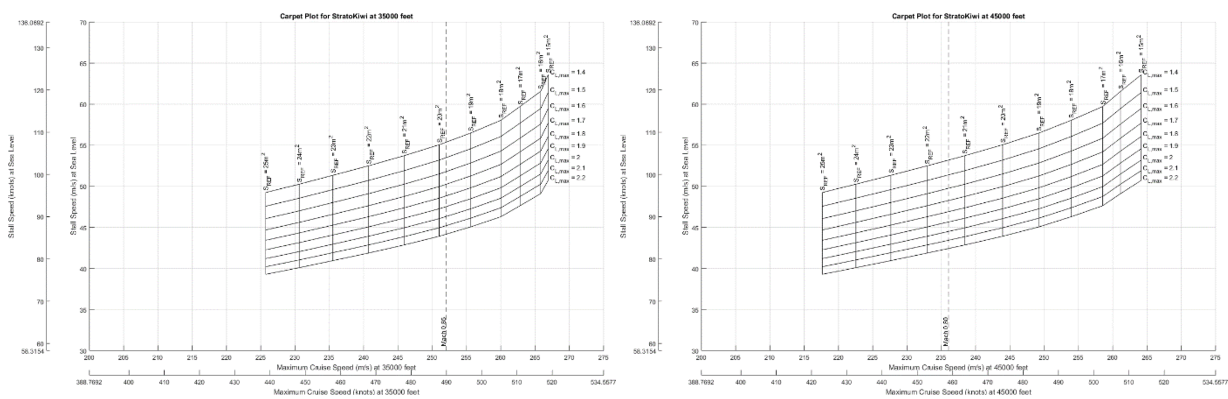


Figure 3-7: Carpet Plot for StratoKiwi

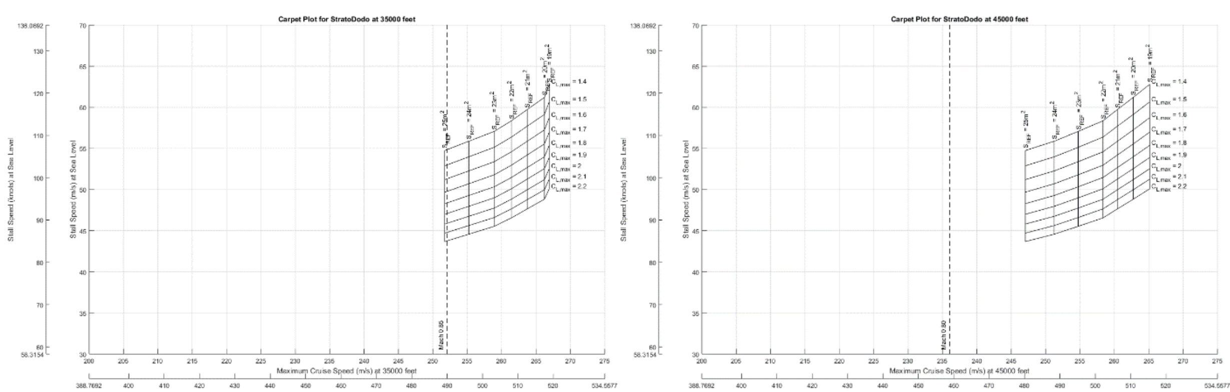


Figure 3-8: Carpet Plot for StratoDodo

3.4. Aircraft Configuration Study

To determine the aircraft configuration to be implemented for StratoKiwi and StratoDodo, an extensive discussion was done to find a configuration that is unique and original but still allows the DRO to be fulfilled. In order to quantify the discussion, several evaluation criteria were identified based on the RFP and the DRO and any possible aircraft configurations were listed and then scored for each evaluation criteria based on team discussion. From the total score accumulated from all evaluation criteria, several candidate were found and then discussion further to justify its selection. These evaluation criteria, possible aircraft configuration, its scoring, and the final configuration candidate can be seen in the following Table 3-5.

For wing configuration, mono-plane wing with swept-back angle was quickly agreed upon. However, the selection of tail configuration took quite some time until it was agreed to proceed with outboard horizontal and vertical stabilizer (OHVS) configuration. In the discussion, OHVS configuration was argued to provide huge aerodynamic advantage due to the fact that horizontal stabilizer (HTP) in this configuration is positioned within wing upwash area, thus providing drag-free upward lift. However, in order for this configuration to work, aircraft's CG must be placed within wing's aerodynamic center (AC) and HTP's aerodynamic center and this might lead to stability problem. The fact that all tail planes are installed on the wing tip was also worried that it will lead to structural issues. Because of this, the more conventional inverted V-tail was also considered as it also provide visual uniqueness with some advantages in terms of handling quality. However, after more detailed study on OHVS configuration was done, it was concluded that the OHVS configuration is feasible for implementation and it was agreed to use OHVS configuration for StratoKiwi and StratoDodo.

While it was agreed to use OHVS configuration for StratoKiwi and StratoDodo, based on Darrenougue[4] and Kentfield[8] several design constraints must be upheld in order to make the OHVS beneficial. These design constraints are listed in the following:

- Wing's AC must be located in front of aircraft CG for trim as upwash in OHS is only beneficial if the OHS generates upward lift.
- OHS must be located far enough behind main wing to allow the development of tip vortex. Minimum distance of twice of wing's mean aerodynamic chord (MAC) in between wing's 25% tip chord and OHS' 25% root chord is suggested.
- OHS half-span must not exceed twice wing's mean aerodynamic chord (MAC) in order to keep the whole OHS immersed in the upwash.
- OHS must generate lift at lift coefficient of at least 50% of wing's lift coefficient to ensure sufficient control margin for pitch and roll.
- Wing surface should be reduced to in order accommodate sufficient lift coefficient ratio to OHS.

Another issue that were also discussed for quite some time is whether to use twin embedded engine configuration at aft fuselage or the conventional pylon mounted twin engine configuration. Embedded engine configuration is appealing to be combined with OHVS configuration as the aft fuselage is free from empennage in this configuration. While embedded engine configuration may lead to reduction of installed thrust due to boundary layer ingestion, inhomogeneous flow at fan station, and pressure recovery losses, this effect was argued to be compensated by pressure drag reduction of the fuselage. Embedded engine configuration also lead to less exposed wetted surface area of the entire aircraft that will reduce the total skin friction drag. Study conducted by Plas[1] shows that these contradicting effects ultimately lead to insignificant SFC reduction of 0.43%, and thus, means that this configuration is not a bad idea. Moreover, in case of one engine inoperative (OEI), embedded engine configuration will also lead to slower minimum control speed due to its short thrust moment arm length. Maintenance difficulty issue is to be expected from embedded configuration, however it was argued that it will not play a significant factor. Ultimately, it was agreed to use embedded engine configuration for StratoKiwi and StratoDodo.

Table 3-5: Aircraft Configuration Evaluation Matrix

Evaluation Criteria		Aero-dynamic Quality	Handling Quality	Structure Design	Acqui-sition	Mainte-nance	Safety Feature	Visual Appeal	Tech. Maturity	Total Score
Weighting Factor		4	3	4	5	2	2	3	5	
Engine Configuration	Single Engine at Aft Fuselage	4	1	3	4	4	1	3	5	95
	Twin Engine under Wing	3	3	3	5	5	2	1	5	100
	Twin Engine above Wing	3	3	3	5	3	2	4	4	100
	Twin Engine under Wing and One Engine at Aft Fuselage	2	5	2	3	2	4	3	3	82
	Twin Engine at Aft Fuselage	4	2	4	5	3	3	1	5	103
	Twin Engine embedded at Aft Fuselage	5	2	1	1	1	4	5	2	70
	Three Engines at Aft Fuselage	4	4	2	3	2	5	3	3	89
	Three Engines at embedded Aft Fuselage	5	4	1	1	2	5	5	2	80
Wing Config	Mono-Plane Wing	3	3	3	5	3	3	2	5	101
	Bi-Plane Wing, Joined at Mid Wing	4	4	4	3	3	3	4	1	88
	Bi-Plane Wing, Joined at Wing Tip	4	4	4	3	3	3	4	1	88
Wing Swept Configuration	No-Swept Wing	4	3	3	4	3	3	3	5	103
	Swept-back Wing	5	3	2	4	3	3	5	4	104
	Forward Swept Wing	2	4	3	5	3	3	2	5	100
	Asymmetric Swept Wing	5	2	2	1	1	2	4	1	62
	Variable Swept Wing	5	3	1	2	1	2	3	2	68
Tail Configuration	Conventional Tail	2	3	3	5	3	3	2	5	97
	T-Tail	4	3	2	4	3	2	1	5	91
	Crucifix Tail	3	3	3	4	3	3	2	4	91
	Outboard Stabilizer (OHVS)	5	5	1	4	3	3	5	2	96
	V-Tail	4	2	3	3	3	2	5	3	89
	Inverted V-Tail	4	5	4	2	3	2	4	3	94
	Canard with Conventional Vertical Tail	1	3	5	4	3	1	3	4	90
	Canard with Outboard Vertical Tail	2	3	4	3	3	1	3	4	85

4. Preliminary Component Sizing

Based on the results of the initial sizing and the selected aircraft configuration, design process was continued by sizing each aircraft component dimensions individually in order to be able to fulfill their own purposes. Due to the contradicting requirements between two or more components and due to the interdependency between some components, an initial dimensions were agreed upon as a starting point and then several iterative changes and compromises were made until the final dimensions that satisfies the requirements of each component was achieved. In this chapter, the sizing iteration process of each component will be described and the final sizing of each component will be outlined.

4.1. Implementation of Family Concept and Airframe Commonality

One of the most important item addressed in the DRO is the shared airframe weight that comes from the family concept requirement. This objective allows high cost saving potentials in non-reoccurring cost associated with the development of design, set-up of production machinery and tools, testing, and certification. Having a large number of repetitive assembly parts would facilitate also a faster learning effect for the assembly line workers and line maintenance staff, leading to higher efficiencies as well as lower error rate in their operations. Nevertheless, since this will dictates the design process, its implementation into the aircraft design must be thought of before proceeding with the preliminary sizing. In order to comply with the difference in needs concerning passenger number, cargo capacity, fuel capacity, and wing surface area for StratoKiwi and StratoDodo, there shall be structural differences in the fuselage and wings for these two aircrafts and this was thought to be realized in terms of wing extension, fuselage extension, and additional fuel tank.

4.1.1. Fuselage Extension and Extra Fuel Tank

In order to accommodate the additional cabin salon as well as the cargo area, additional frames of fuselage are added to StratoDodo's fuselage. A cabin extension of 1.3 m is added before the shared passenger cabin for and a cargo extension of 1.37 m is added behind the shared cargo segment. These extensions are attached to the front and back of the shared cabin & cargo segment in order to not cross over the wingbox junction to fuselage. This fuselage extension concept is shown in detail by Figure 4-2 under the fuselage sizing section. In order to accommodate the additional 0.36 m^3 of fuel needed by StratoDodo, additional fuselage fuel tank will be added to StratoDodo. This extra tank will be located under the floor of the cargo extension segment with tank length of 0.67m. This extra fuel tank placement can be seen in Figure 4-6.

4.1.2. Wing Extension

In order to achieve an additional wing surface area of 2.71 m^2 for StratoDodo as required by the results of the selection of design points summarized in Table 3-4, a wing extension piece is planned. There are multiple possibilities on where this wing extension can be attached, each with their own consideration as listed in Table 4-1 below. After weighing all the options, it was decided to put the extension piece in the middle of the wing.

Table 4-1: Consideration Table for the Placement of Wing Extension

Location of Wing Extension	Considerations	Selection
At wing root (as the inboard segment of wing)	Difficult to have a shared bay structure for landing gear.	X
In the middle of wing (as the middle segment of wing)	No significant difficulties.	V
At wing tip (as the outboard segment of wing)	◦ Small wing tip chord leads to a long increase in span in order to reach the required additional surface area. This leads to structural weakness ◦ Joint to empennage become complex complex and requires high structural integrity. This leads to higher weight if both the unextended wing tip and the extension segment require an interface to join the empennage.	X

With this concept, the complete wing geometry thus will be divided into three segments: inboard segment, middle segment, and outboard segment. The middle segment shall be deemed as the extra surface area for StratoDodo and will not be used for StratoKiwi. In order to ensure that the wing can be assembled with or without the additional middle wing segment, the middle segment is designed to have a parallel leading edge and trailing edge. This allows the chord length of this segment to be identical at root and at tip, thus allowing the inboard segment to be mechanically attached to the middle segment for StratoDodo, and that the outboard segment to be attached to the tip of this middle segment as if it was an inboard-segment joint. For StratoKiwi's wing, the inboard segment will be joined directly to the outboard segment.

4.1.3. Estimation of Total Shared Structure Weight

Other than fuselage extension and wing extension mentioned above, all other structures and most of the aircraft system will be shared between StratoKiwi and StratoDodo. The detailed list of shared structure and system weight between the two aircraft can be observed from Table 4-7 and from this class II weight component break-down, a total shared weight of 2857 kg was estimated. This is 95% and 82% of StratoKiwi and StratoDodo's total empty weight.

4.2. Engine Selection

The purpose of engine selection and nacelle sizing is to ensure that the total installed thrust delivered in any flight phase and condition is sufficient for the aircrafts to perform its mission. However, since StratoDodo and StratoKiwi are designed as family aircrafts, before choosing any engine, it should be decided first whether to use same engine for both aircrafts or not. These two options were studied and in the end, it was decided to use the same engine for both aircraft for the reason of acquisition cost reduction and component interchangeability. As the consequence, engine selection must be based on the need of StratoDodo and this will lead to an overpowered engine for StratoKiwi. Nevertheless, derating the engine for StratoKiwi can be done to solve this problem but it will not be taken into consideration in this work.

From the selection of design point shown in Table 3-4, it was shown that the required take-off thrust for StratoDodo is 22.59 kN (5054 lbs). Since this is an installed thrust value, engine with around 10% higher uninstalled thrust rating was desired. With this uninstalled thrust requirement, several engine such as GE Honda HF120, Pratt Whitney PW530, and Williams FJ44 were identified and considered. However, eventually engine selection leaned towards FJ44 as this engine is widely used by competitor aircrafts and has a wide variety of model and thrust rating to choose from. Three varieties for FJ44 engine as shown in Table 4-2 were considered and ultimately FJ44-3A was chosen because of its high thrust rating.

After FJ44-3A was selected, its installed thrust and SFC at various flight altitude and Mach number must be estimated for performance calculation. Roskam[18] suggests to use manufacturer data and correct it for installation factor, however, since the manufacturer data is not available, an interpolation was done instead based on the installed engine performance data table of FJ44-3E provided by Nikolai[9]. The following Figure 4-1 shows the resulting interpolation results for installed engine thrust and specific fuel consumption at various altitude and Mach number.

Table 4-2: Engine Candidates for StratoKiwi and StratoDodo (Nikolai [9])

Engine Model	Uninstalled SLS Thrust	Dry Weight	Length	Fan Diameter	Bypass Ratio
FJ44-3A	13.45 kN (3000 lbs)	222 kg (490 lbs)	1219 mm (48 in)	584 mm (23 in)	4.1
FJ44-3A-24	10.68 kN (2400 lbs)	243 kg (490 lbs)	1219 mm (48 in)	584 mm (23 in)	4.1
FJ44-3E	12.01 kN (2700 lbs)	243 kg (490 lbs)	1219 mm (48 in)	584 mm (23 in)	4.1

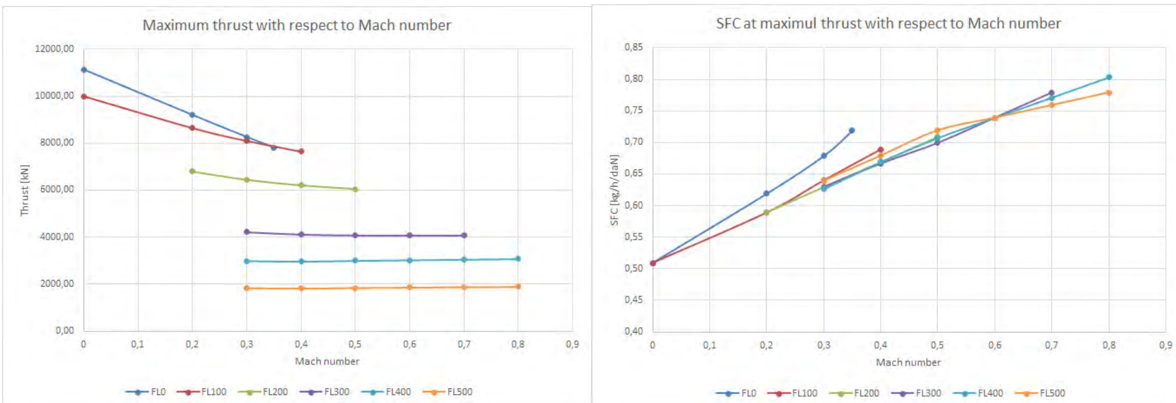


Figure 4-1: Estimated Installed Engine Performance for Williams FJ44-3A

After FJ44-3A was selected, nacelle sizing was done to ensure that the inlet can provide enough mass flow for combustion and cooling. This was done relatively straight-forward based on Roskam[18] without involving any iterations. With the required mass flow found, along with the selected cruise speed and cruise altitude, it was found that the required area inlet is 0.257m^2 (2.766 ft^2).

4.3. Fuselage Sizing

The main purpose of fuselage sizing is to provide enough spaces for the aircraft to carry its payload and systems while providing structural support for all aircraft components. For preliminary phase, fuselage sizing only includes determining fuselage length and its diameter. However, since StratoKiwi and StratoDodo is a business jet, fuselage sizing must be done with special attention on passenger comfort. As a consequence, fuselage sizing was done based on the need of cabin and cargo compartment.

To determine the initial fuselage length, cabin length and cargo compartment length must be firstly determined. Cabin length was approximated according to the number of passengers and the expected level of comfort. The estimation values used for each cabin compartment was summarized in Table 4-3 below. Both aircrafts are expected to contain a lavatory and a small galley. With each salon having total length of 2.2 m for passenger seats, StratoKiwi was sized to have 1 salon for 4 passengers with the 5th passenger seated on a belted lavatory seat or opposite of the small galley) and the 6th passenger seated on the co-pilot seat. StratoDodo, on the other hand, shall have 1.5 salons for 8 passengers. These values were adapted from statistical values suggested by Dassault[5].

Table 4-3: Fuselage Compartment Length Estimation

Fuselage Component		StratoKiwi	StratoDodo
Cockpit Length	[m]	3.5	3.5
Cabin Total Length	[m]	4.1	5.4
Lavatory Length	[m]	0.6	0.6
Galley Length	[m]	1.1	1.1
No. of Salons	[-]	1	1.5
Length per Salon	[m]	2.2	2.2
Separation walls	[m]	0.2	0.4
Cargo Length	[m]	1.36	2.73
Luggage Mass	[kg]	226.8	453.6
Section Area	[m^2]	2.22	2.22
Luggage Density	[kg/m^3]	150	150
Stacking efficiency	-	50%	50%
Bulkhead length	[m]	4.44	4.44
Total Fuselage length	[m]	13.4	16.07

For the cargo compartment, the DRO requires both aircrafts to be able to carrying 226.8 kg (500 lbs) and 453.6 kg (1000 lbs) of luggage respectively. To accommodate this need, the required volume was computed based on the cross section of the cabin, luggage density, and stacking efficiency. Dassault[5] estimates a luggage density of 150 kg/m^3 and a stacking efficiency of 70% for luggage compartments in business jets. However, for StratoKiwi and StratoDodo, stacking efficiency of only 50% was assumed due to the walk-in luggage zone design, as the space needed for a person to walk in can't be utilized. Note due to lower statistical luggage density applied here, the luggage volume available for both aircrafts is larger than the one requested in the DRO. This allows the passengers to travel with bulkier luggage if needed.

Other than the cabin and cargo compartments, the cockpit length was estimated to be 3.5m, a common value for this magnitude of aircrafts according to Dassault[5], and the rear bulkhead was also estimated to be 4.44m, based on the fuselage diameter. In the end, as summarized in Table 4-3, total fuselage length was estimated to be 13.4m for StratoKiwi and 16.07 for StratoDodo.

For fuselage diameter, it was initially desired to have fuselage diameter of 2.5 m with 1.75 m cabin height in mind. This was an attempt to provide maximum cabin comfort as well as enough space for fuel tank. However, during design iterations, it was found that this fuselage size led to huge skin friction drag and the desired cruise lift-to-drag ratio couldn't be achieved. Thus, to reduce improve the lift-to-drag ratio, compromise was made and fuselage diameter was scaled down to 2.3m with 1.55 m cabin height.

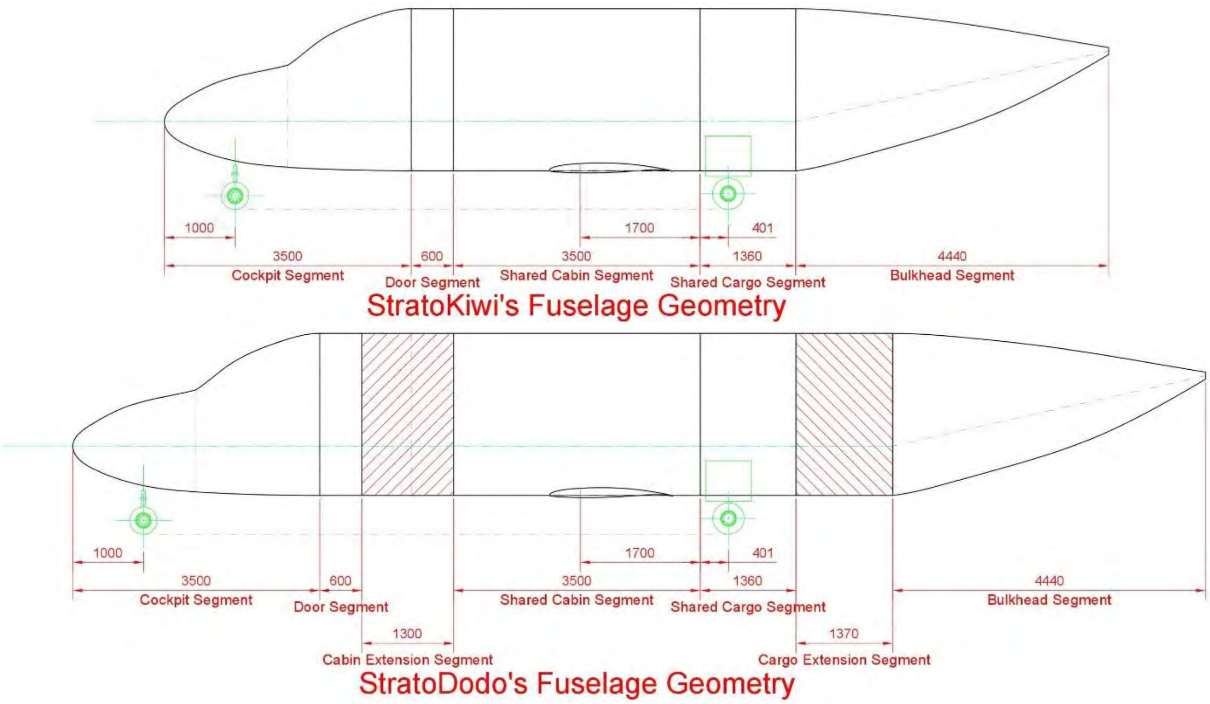


Figure 4-2: Fuselage Geometry (Dimensions in mm)

4.4. Wing Sizing

The purpose of wing sizing is to provide sufficient lift in any flight phase and condition with minimal drag. This means that the wing must be able to generate enough maximum lift coefficient for a safe take-off and landing and at the same time provide a good drag polar that will allow the aircraft to be efficient in cruise. For this purposes, wing sizing was done in three step. These three steps and the sizing result of each step will be outlined in the following sections.

4.4.1. Wing Planform Sizing

From the design objectives shown in Table 3-3 and matching chart results shown in Table 3-4, several requirements for wing shape parameters were already identified and initial wing planform sizing was done to satisfy these requirements. To accommodate the difference in the required wing surface area, the wing was designed to consist of two segments (inboard and outboard) that are shared between StratoKiwi and StratoDodo and an additional middle segment that is added in between the inboard and outboard segment for StratoDodo in order to achieve higher wing surface area and aspect ratio. As both aircrafts will be cruising at Mach number of 0.8, swept-back angle of at least

15° was chosen in order to have critical Mach number higher than 0.85. For dihedral angle, moderate positive equivalent dihedral angle was chosen to provide some spiral stability and ground clearance.

During the design iteration, longer tip chord was deemed necessary to sustain load from the OHVS. However, doing so would lead to lower wing aspect ratio and higher taper ratio that hinder the cruise performance. Ultimately, after several iterations on drag polar, a compromise was made to accommodate longer tip chord length and this led to a shift in design point as shown by the red dot in Figure 3-5 and Figure 3-6. Ultimately, the final iteration of wing planform parameters were listed in the following Table 4-4 while its geometry is shown by Figure 4-3. Note that StratoKiwi equivalent and StratoDodo equivalent segments in Table 4-4 refers to the equivalent straight-tapered planform parameters of each aircraft respectively. These equivalent planform parameter was determined by using AAA software. On the other hand, the hatched wing area shown in Figure 4-3 refers to the middle segment that is applied only for StratoDodo.

Table 4-4: Wing Planform Shape Parameters

Segment Name	Planform Parameter						
	$b_{0.5}$	c_r	c_t	i_r	i_t	$\Lambda_{c/4}$	Γ
	Half Span	Root Chord	Tip Chord	Root Incidence	Tip Incidence	Swept Angle	Dihedral Angle
	[m]	[m]	[m]	[deg]	[deg]	[deg]	[deg]
Inboard Segment	2.50	1.75	1.25	0.00	0.00	15.00	10
Middle Segment	1.16	1.25	1.25	0.00	0.00	17.64	5
Outboard Segment	4.00	1.25	1.00	0.00	0.00	16.82	5
StratoKiwi Equivalent	6.50	1.54	1.00	0.00	0.00	15.4	6.92
StratoDodo Equivalent	7.66	1.53	1.00	0.00	0.00	15.3	6.63

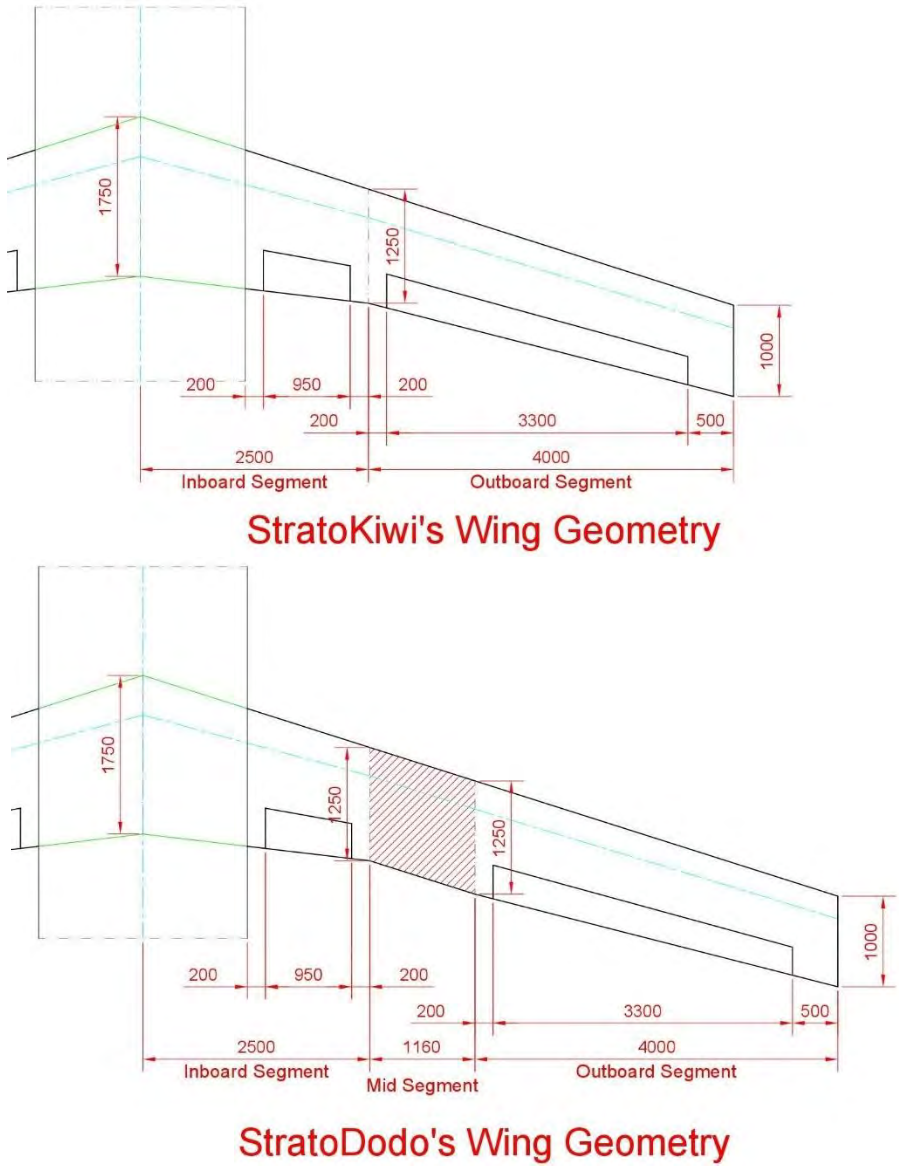


Figure 4-3: Wing Planform Geometry (Dimensions in mm)

4.4.2. Wing Airfoil Selection

For the selection of wing airfoil, three main parameters that were considered important are its maximum lift coefficient ($C_{l,max}$), maximum lift-to-drag ratio (LoD), and its maximum thickness (t/c). Since StratoKiwi and StratoDodo will perform cruise at Mach number of 0.8, supercritical airfoil naturally came into mind for this purpose. Thus, four available supercritical airfoils were surveyed and its aerodynamic characteristics were evaluated using XFOIL software. XFOIL evaluations were done for Reynolds number of 5×10^6 and Mach number of 0.126 and Table 4-5 below summarizes the results.

Table 4-5: Supercritical Airfoil's Aerodynamic Characteristics

Supercritical Airfoil Candidates			
Airfoil Name	$C_{l,max}$	t/c	LoD_{max}
KC135winglet-il	1.933	0.0796	129.744
SC(2)-0714	2.1697	0.1394	76.011
SC(2)-0412	2.0207	0.12	93.854
Whitcomb-il	2.0995	0.1096	88.232

Based on these results, it was decided to choose KC135winglet as wing's airfoil due to its maximum lift-to-drag ratio and its maximum lift coefficient. However, it was also noticed that this airfoil is relatively thin (8% thickness) and only allow smaller fuel tank capacity inside the wing. Thus, fuselage fuel tank became necessary. Nevertheless, it was agreed that the high maximum lift-to-drag ratio outweighed the need to put all fuel tank inside the wing. With KC135winglet selected, further detailed XFOIL evaluation was done to find the complete aerodynamic characteristic that are needed for further detailed calculation. These characteristics are shown in Table 4-6 and Figure 4-4 below.

Table 4-6: Aerodynamic Characteristics of KC135winglet Airfoil

$C_{l,\alpha}$	Lift Slope	[deg^{-1}]	0.1153
$C_{l,max}$	Maximum Lift Coefficient	[-]	1.9330
α_0	Zero-Lift Angle-of-Attack	[deg]	-4.5
$C_{l,0}$	Zero AOA Lift Coefficient	[-]	0.5651

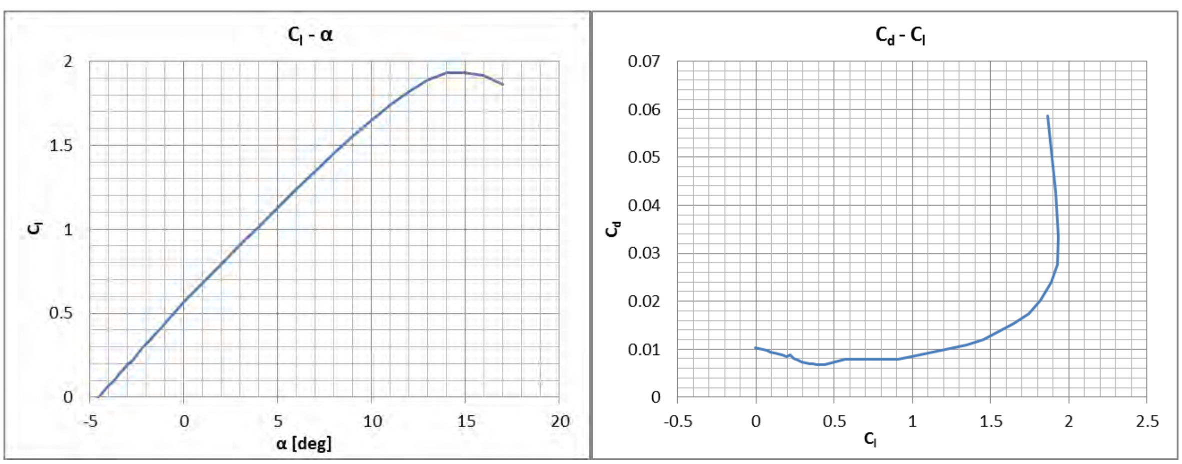


Figure 4-4: Lift Polar and Drag Polar for KC135winglet Airfoil

4.4.3. Flap Sizing for Take-Off and Landing

During the selection of design point, design objectives for maximum lift coefficient in various flap configuration was defined as shown previously in Table 3-3. To ensure that these maximum lift coefficient was achieved, flap sizing is obviously necessary. Thus, an appropriate type of flap must be chosen and sized accordingly. After several discussion and considering that the requirement for maximum lift coefficient are not too high, plain flap was chosen for its simplicity. As for the flap size, initial estimation of 30% chord ratio was assumed with consideration that any space from 15% wing chord to 65% wing chord will be used for fuel tank. On the other hand, flap deflection angle was assumed to be 15˚ and 60˚ for take-off and landing configuration respectively.

With all the parameters mentioned above, simple calculation based on Roskam[14] was done and the result shows that flap area ratio of 0.4186 for StratoKiwi and 0.5149 for StratoDodo are required to achieve the desired maximum lift coefficient. With this flap area ratio, flap must be installed at both the inner segment and outer segment of the wing as the inboard segment of the wing does not provide enough flap area ratio. This was not seen as a problem as the lateral control surface was planned to be placed at the OHS in forms of elevon. Ultimately, it was decided to extend the flap though out the whole inboard and outboard segment in order to provide more lift coefficient during take-off and landing. A margin of 0.2m (0.656ft) was provided at each side of inboard and outboard segment to avoid manufacturing issue while the middle segment was not used as this segment is only available for StratoDodo. The arrangement and positioning of flap can be seen in the previous Table 4-4 and in this figure, the flap area ratios are 0.8475 and 0.7204 for StratoKiwi and StratoDodo respectively.

4.5. Component Arrangements and CG Management

The purpose of component arrangements is to ensure that all aircraft components (both external and internal) are placed appropriately while at the same time ensuring desirable CG location at any flight phase and condition. CG management is exceptionally important in OHVS configuration as it allows only a short stretch of CG location. For the OHVS configuration to function properly, CG location must be located between wing's AC and HTP's AC where in this CG location. However, at the same time, CG location must be still behind the aircraft's AC for the aircraft to be stable and within reasonable distance proportion from nose landing gear (NLG) and main landing gear (MLG) for a proper load distribution between each landing gear. In order to obtain the desired CG location and limit its travel, numerous iteration were done to find proper location for each component.

Since in OHVS configuration, all tail planes are mounted on the wing tip, component arrangement was started by determining wing position in longitudinal direction and its swept angle as swept angle is the only parameter that allow the distance between wing's AC and HTP's AC to be manipulated. After that, internal system arrangement was done followed by class I component weight break-down and CG determination method proposed by Roskam[16].

Special attention was taken to determine the position of fuel tank within fuselage since it greatly affect CG travel. Iterations were done until the desired CG travel was obtained. In the end, class II component weight break-down and CG determination proposed by Roskam[16] was done to confirm the desired CG travel. Figure 4-5 and Figure 4-6 shows the aircraft component arrangement for the final iteration while Table 4-7 below shows its results of class II component weight break-down and CG determination. From the same CG determination, CG travel for various loading scenario was also estimated and its results are shown by the following Figure 4-7 and Figure 4-8. Note that in these figures, CG location are measured from a reference point located 10 m in front of the aircraft nose while the dashed line represent the location of wing's AC and HTP's AC.

Table 4-7: Weight and Balance Estimation Table

Component Weight Break-Down	Stratokiwi		StratoDodo		Shared Weight
	Weight	Longitudinal CG Location	Weight	Longitudinal CG Location	
	[kg]	[m]	[kg]	[m]	[kg]
Fuselage	599	5.23	821	6.27	599
Wing	299	6.69	456	8.00	299
Empenage - HTP	53	11.64	53	13.31	53
Empenage - VTP	79	11.38	79	13.05	79
Empenage - Boom	152	9.28	152	10.95	152
Nacelle	151	9.97	151	12.64	151
Powerplant - Engine	445	10.22	445	12.89	445
Powerplant - Starter System	38	10.22	38	12.89	38
Powerplant - Control System	12	10.22	12	12.89	12
Landing Gear - Nose	40	1.00	40	1.00	40
Landing Gear - Main	176	8.00	176	9.30	176
Fixed Equipment					
Fuel System	124	7.40	124	9.24	111
Flight Control System	54	4.02	62	4.82	48
Hydraulic System	69	4.02	69	4.82	62
Electrical System	133	4.02	144	4.82	120
Avionics and Instrument	145	4.02	145	4.82	131
Pressurizantion System	85	8.96	121	11.63	77
Oxygen System	19	4.02	21	4.82	17
APU System	56	8.96	56	11.63	50
Cabin Furnishing	174	5.55	233	6.20	157
Baggage Equipment	44	8.28	88	10.27	39
Total Empty Weight and CG	**2947**	**7.22**	**3488**	**8.56**	**2857**

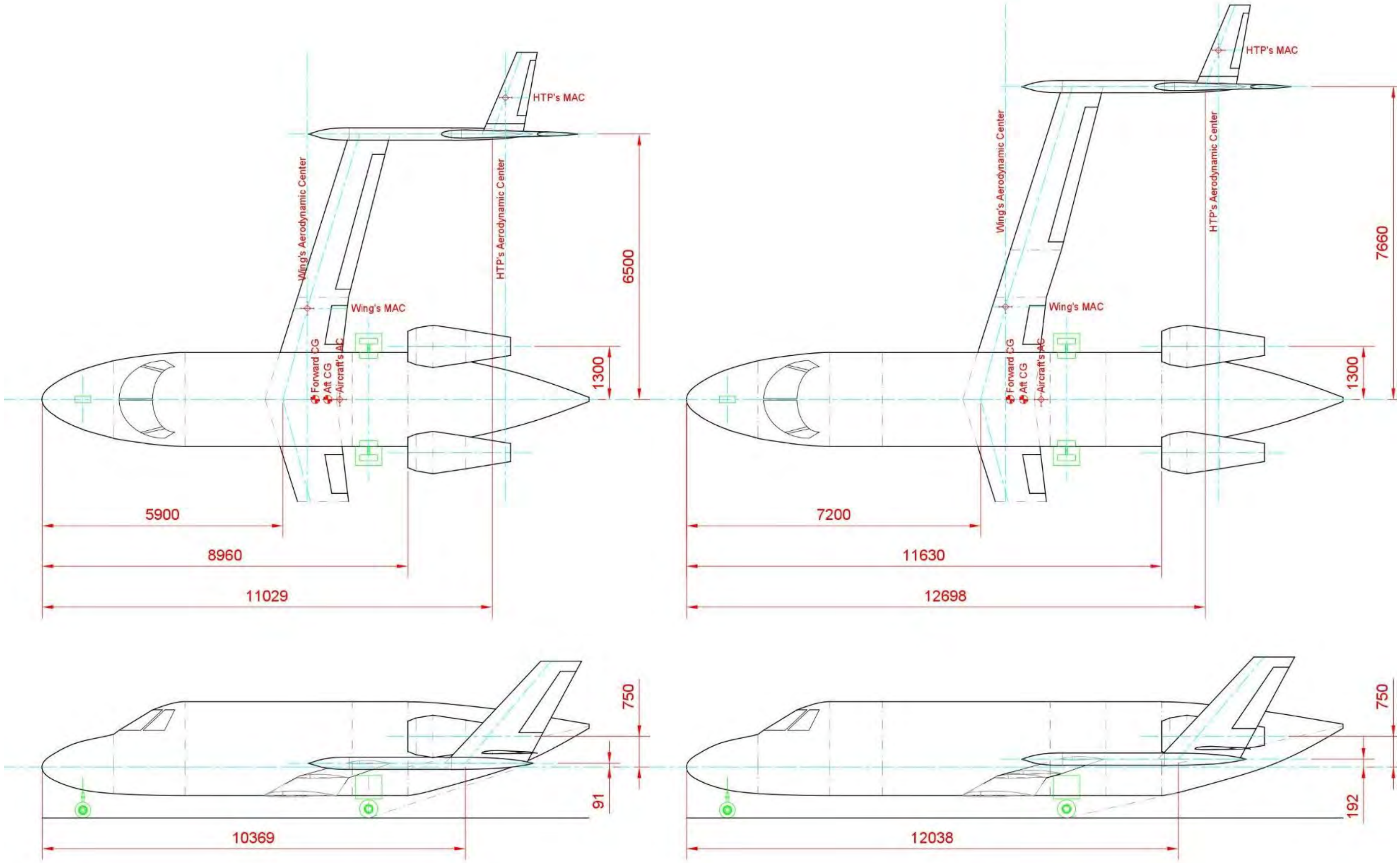


Figure 4-5: External Component Arrangement for StratoKiwi (left) and StratoDodo (right)

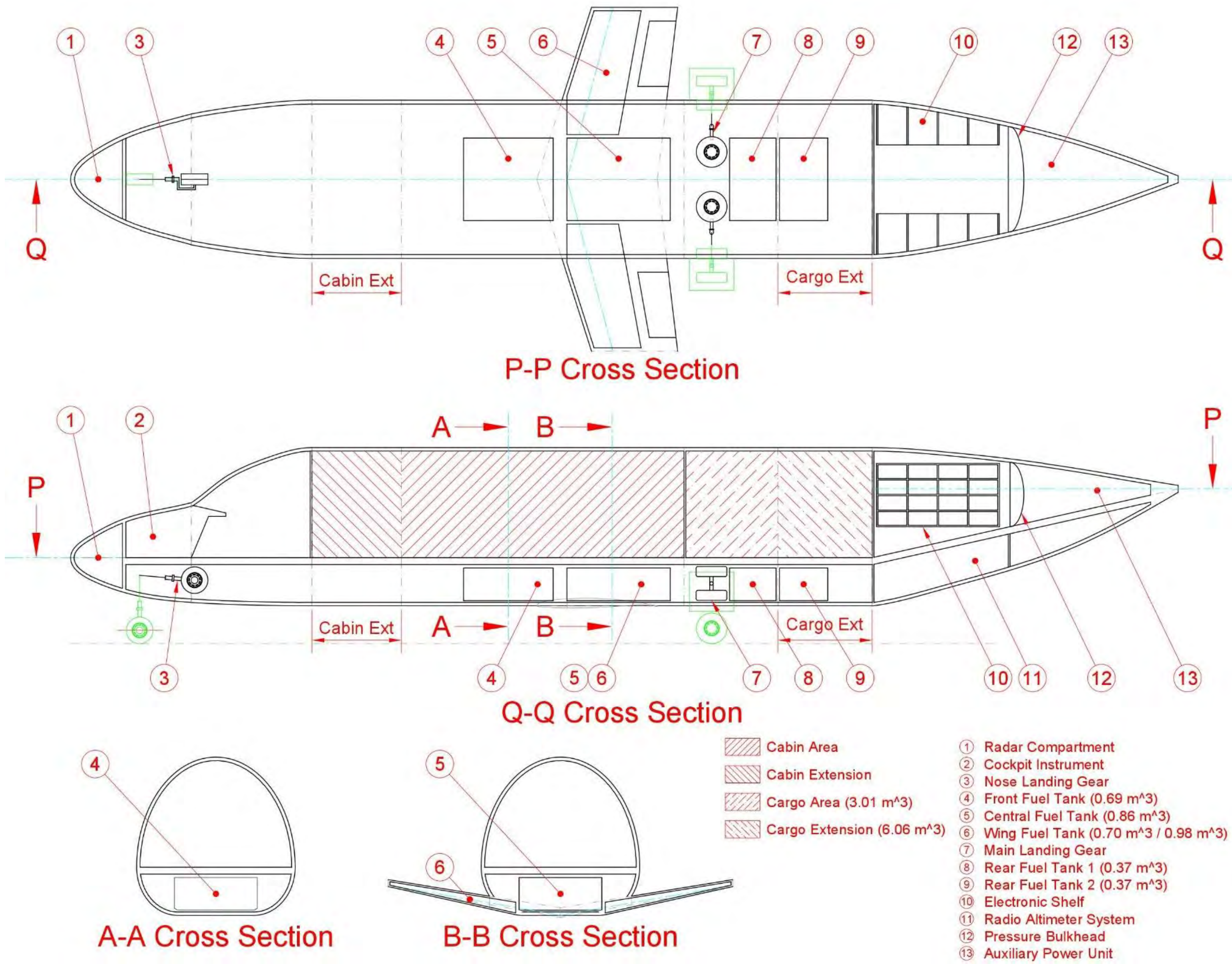


Figure 4-6: Detailed System Arrangement for StratoKiwi and StratoDodo

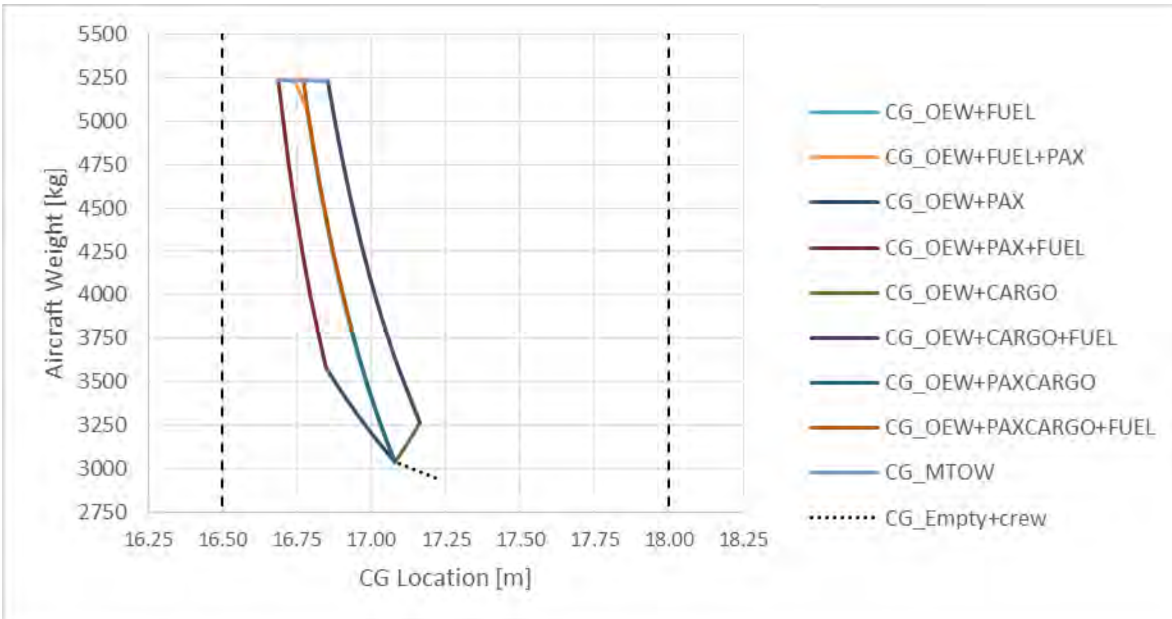


Figure 4-7: CG Travel Diagram for StratoKiwi

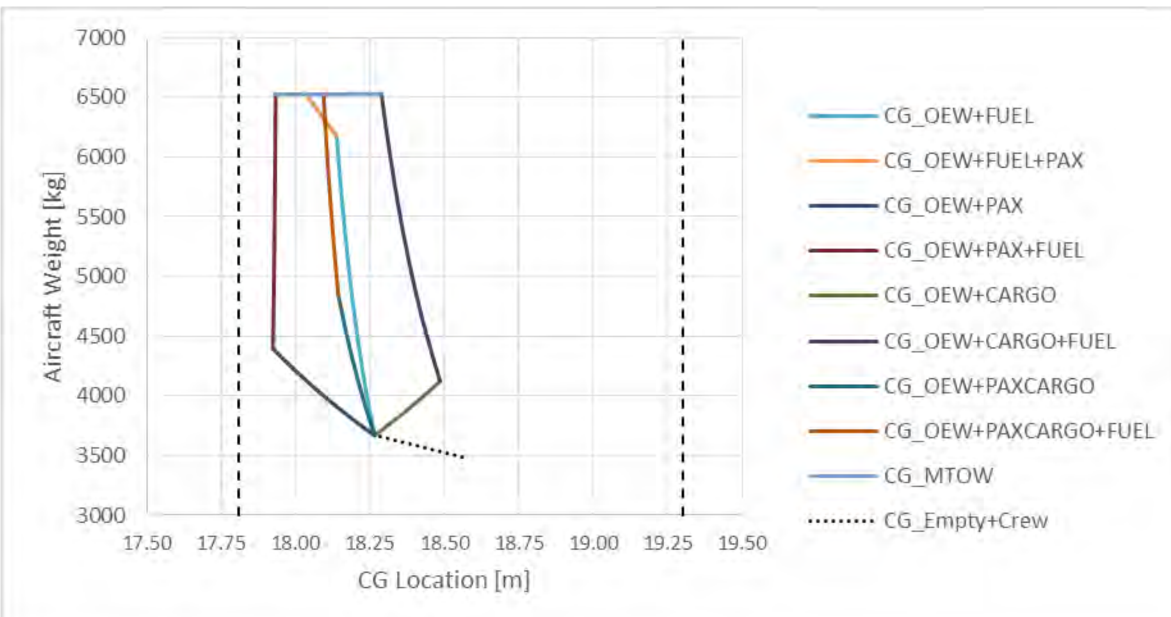


Figure 4-8: CG Travel Diagram for StratoDodo

4.6. Empennage Sizing

The main purpose of empennage sizing is to ensure aircraft's stability and controllability in any flight phase at any allowed CG location. Empennage sizing includes sizing the empennage's planform and its control surface and choosing the airfoil for it. Typically, this only involves HTP and VTP. However, since OHVS configuration was implemented for StratoKiwi and StratoDodo, a tip boom is necessary to support the HTP and VTP and should be considered as well. It should also be kept in mind that since empennage sizing requires the knowledge of aircraft's CG location, it was done in conjunction with component arrangement and CG management outlined in section 4.5.

For preliminary sizing phase, empennage planform sizing is done by assuming that the aircraft need to have roughly similar tail volume coefficient with its competitor aircrafts. While these tail volume coefficient data was hard to be obtained for competitor aircrafts due to the fact that it requires the knowledge of the aircraft's CG location, Roskam[14] provides several reference business jet data that can be used. Similar method was also applied for control surface sizing. The required control surface area ratio is assumed to be similar with the competitor aircrafts.

Reference data from Roskam[14] show that typical business jet's tail volume coefficient ranges from 0.51 to 0.99 for HTP and 0.0590 to 0.0930 for VTP. From these reference values, empennage planform for both StratoKiwi and StratoDodo was sized as shown in Table 4-8 and Figure 4-9. Note that to anticipate the shift in CG location during the design iteration that may lead to smaller tail volume, the empennage was sized slightly larger. Ultimately, for the final iteration, this empennage size led to tail volume values summarized in Table 4-9 which shows that the tail volume coefficient falls within the reasonable value for business jet. Note that when sizing the empennage planform, it was actually initially desired to extend tip boom in order to increase the tail volume coefficient for HTP and VTP. However, this was limited by tip boom's torsional loading. Nevertheless, a minimum distance of twice wing tip chord length between wing tip's 25% chord location and HTP's 25% root chord location was provided as suggested by Kentfield[8] in order to allow wing upwash to develop and take advantage of it.

For the longitudinal and lateral control, it was decided to apply variable incidence HTP with a trim tab as shown in Figure 4-9 as both elevon. This decision was taken considering that there is a need to align the HTP with the upwash from the wing in order to maximize the benefit of OHVS configuration. By implementing elevon, it was also realized that complexities on actuator design and placement will be encountered. Excessive roll control problem may also be encountered during high speed flight due to the absence of inboard aileron. Nevertheless, variable incidence HTP was deemed necessary, and it was propose to solve the excessive roll control in high speed flight with the implementation of control laws.

On the other hand, for directional control, conventional rudder was adopted with a slightly large chord ratio of 35%. This decision was taken considering that the lower part of VTP cannot be used due to the possibility of rudder conflict with the variable incidence HTP. The final results of rudder sizing was shown in Figure 4-9 with rudder area ratio of 0.196. This is still falls within the typical range of rudder area ratio shown by reference data from Roskam[14], which is from 0.12 to 0.36 for business jet.

Table 4-8: Empenage Planform Parameter

Segment Name	Planform Parameter						
	$b_{0.5}$	c_r	c_t	i_r	i_t	$\Lambda_{c/4}$	Γ
	Half Span	Root Chord	Tip Chord	Root Incidence	Tip Incidence	Swept Angle	Dihedral Angle
	[m]	[m]	[m]	[deg]	[deg]	[deg]	[deg]
HTP	2.00	1.00	0.50	0.00	0.00	20	0
VTP	1.00	2.00	1.00	-	-	40	-

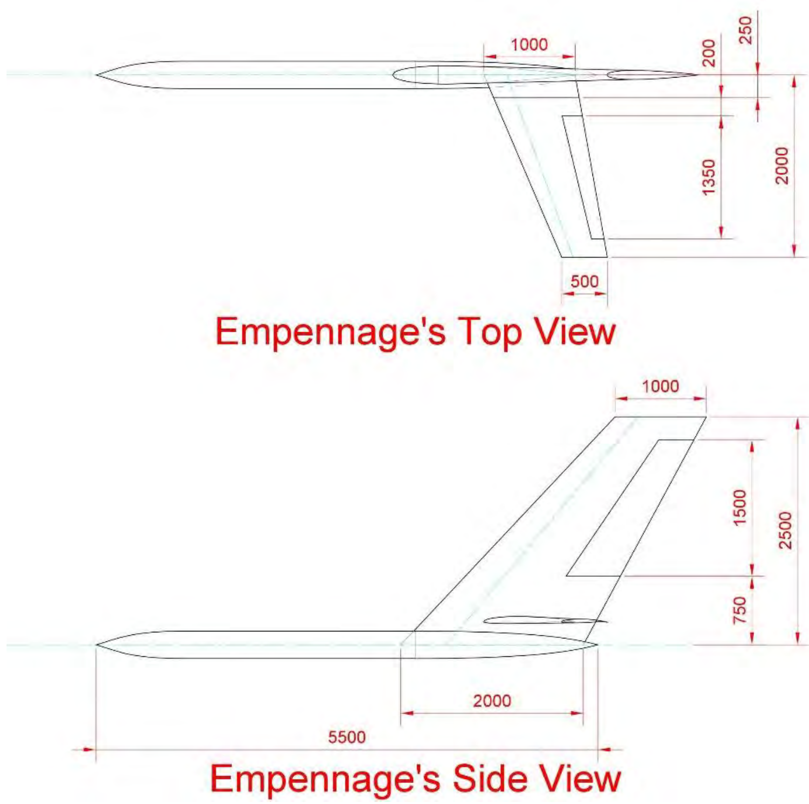


Figure 4-9: Empennage Planform Geometry (Dimensions in mm)

Table 4-9: Tail Volume Coefficient for StratoKiwi and StratoDodo

HTP Tail Volume (Forward CG)	[-]	0.69	0.79
HTP Tail Volume (Aft CG)	[-]	0.61	0.72
VTP Tail Volume (Forward CG)	[-]	0.0807	0.0792
VTP Tail Volume (Aft CG)	[-]	0.0714	0.0725

4.7. Landing Gear Sizing

The purpose of landing gear sizing is to ensure ground stability and proportional loading distribution between nose and main landing gear. This can be translated into five different criteria that are summarized in the following

Table 4-10. In sizing the landing gear, the taken approach was to first assume a position for the NLG and MLG, respectively, and assign the height and track length of landing gear. The status of all criteria was then assessed and if any one of the assessment falls outside of the prescribed limit, the landing gear parameters were iterated until all the requirements are satisfied. Note since the assessment was affected by the location of the most forward and aft CG locations and it will shift slightly as the NLG and MLG were repositioned, landing gear sizing was done in conjunction with component arrangement and CG management outlined in section 4.5.

The results of landing gear sizing are presented in Figure 4-10 for StratoKiwi, Figure 4-11 for StratoDodo, and Table 4-10. Note that since having multiple interface joints to other significant structural components for landing gear is expensive and would diminish the cost reduction benefit achieved by the shared airframe structure, one important consideration during sizing is to ensure that both the NLG bay and MLG bay are placed on shared fuselage segments and also on the same relative locations of the shared section. Due to this constraint, it becomes occasionally necessary to approach the limits of these stability criteria. For both aircrafts, the NLG is placed 1 m from the tip of shared cockpit segment while the MLG is located at 0.96 m behind the start of shared cargo segment.

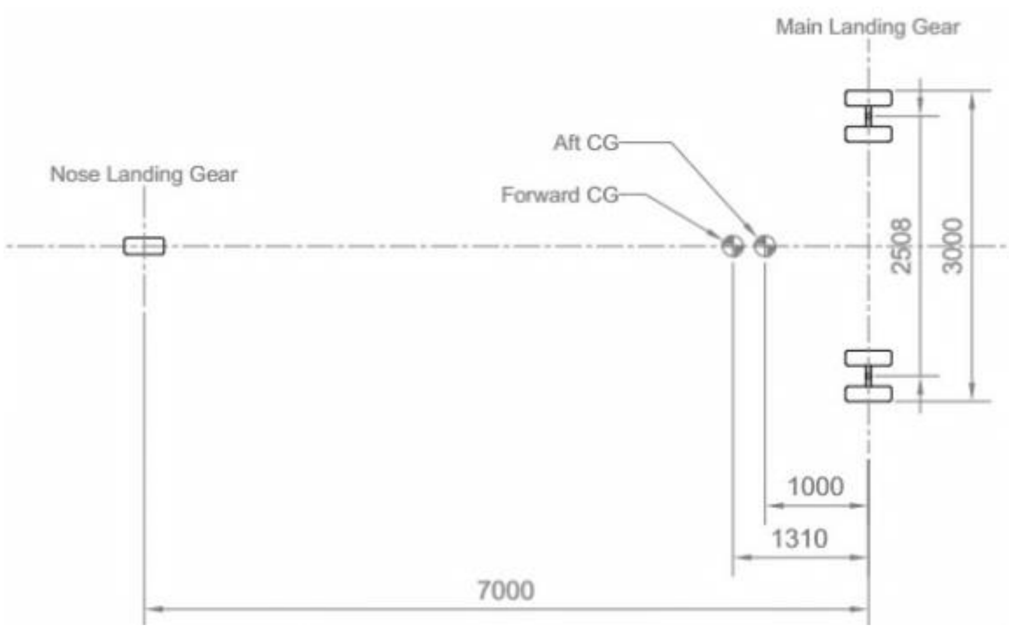


Figure 4-10: Landing Gear Location for StratoKiwi

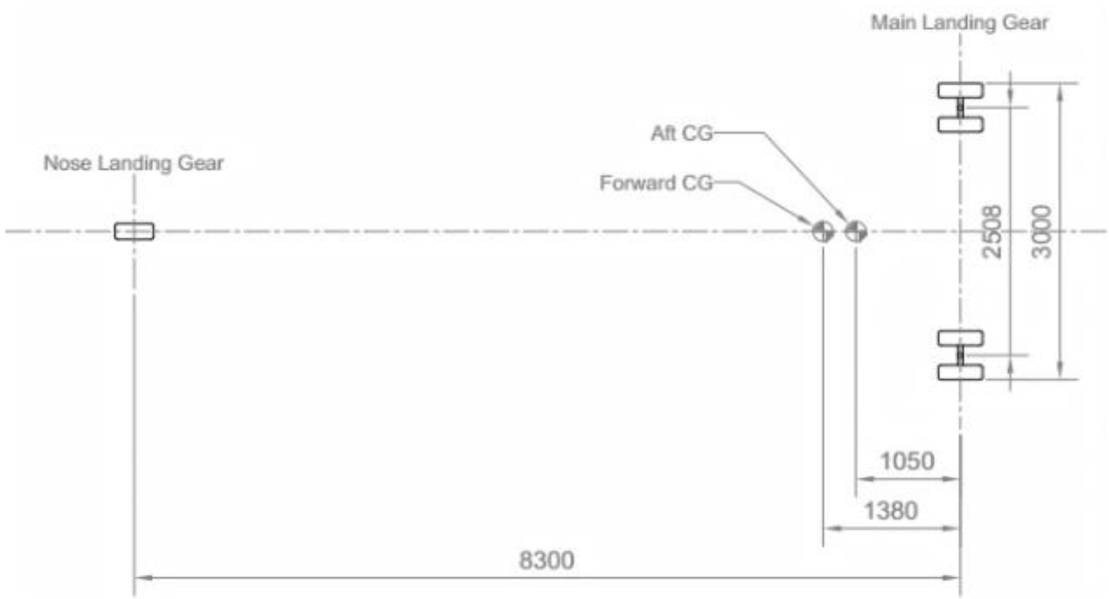
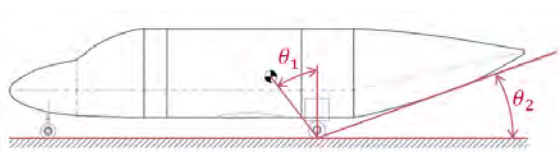
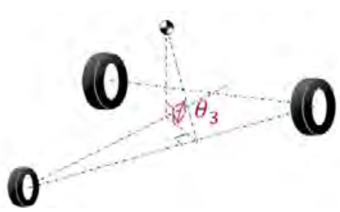
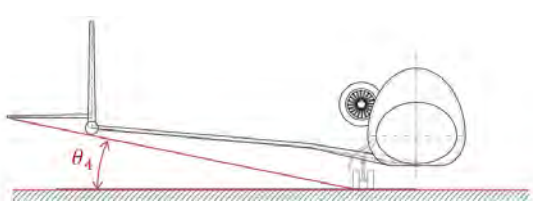


Figure 4-11: Landing Gear Location for StratoDodo

Table 4-10: Landing Gear Assessment Criteria

<table>
<tr><th></th><th></th><th>Kiwi</th><th>Dodo</th><th>Criteria</th></tr>
<tr><td rowspan="2">
Longitudinal Tip-Over and Ground Clearance</td><td>θ_1</td><td>25.5°</td><td>24.7°</td><td>> 15°</td></tr>
<tr><td>θ_2</td><td>19.6</td><td>12.9</td><td>> 12°</td></tr>
<tr><td rowspan="2">
Lateral Tip-Over</td><td>θ_3 (Forward CG)</td><td>52.7°</td><td>51.8°</td><td>< 55°)*</td></tr>
<tr><td>θ_3 (Aft CG)</td><td>54.9°</td><td>54.1°</td><td>< 55°)*</td></tr>
<tr><td>
Lateral Ground Clearance</td><td>θ_4</td><td>12.7°</td><td>11.7°</td><td>> 5°</td></tr>
<tr><td rowspan="2">Static load Percentage on NLG</td><td>Min.</td><td>11.6%</td><td>9.4%</td><td>> 6%</td></tr>
<tr><td>Max.</td><td>18.7%</td><td>16.6%</td><td>< 20%</td></tr>
</table>

5. Aerodynamic and Performance Analysis

After the final iterations of preliminary sizing was reached and agreed upon, design of StratoKiwi and StratoDodo was frozen and more detailed analysis was done to ensure its compliance to the regulation and the DRO. For this, analysis related to aerodynamics characteristics, stability, and flight performance was carried out. Aerodynamic analysis of the complete aircraft was firstly done to estimate the aircrafts' drag and lift polar. From the drag polar and the engine performance characteristic estimated previously in 4.1, the aircraft's flight envelope and cruise performance were estimated. Then, from the obtained lift polar was used to estimate the aircrafts' ground performance. Lastly, more through stability analysis was done with the help of DATCOM software. In this chapter, each of these analysis mentioned above will be described in detail and its results will be outlined.

5.1. Estimation of Drag Polar

Estimation of drag polar is done to ensure that the aircraft's lift-to-drag ratio can achieve the desired value. While its requirement is not explicitly stated in the DRO, it is essential in ensuring several items in the DRO is achievable. Drag polar estimation is usually done by finding individual drag of each aircraft component and summing them up with some interference factor in mind. Since drag itself composed of parasite drag an induced drag, it is also common to estimate an aircraft's drag polar by estimating parasite drag and lift-induced drag individually. For StratoKiwi and StratoDodo, parasite drag was estimated with class II drag estimation method outlined in Roskam[18] while lift-induced drag was estimated based on Raymer[11].

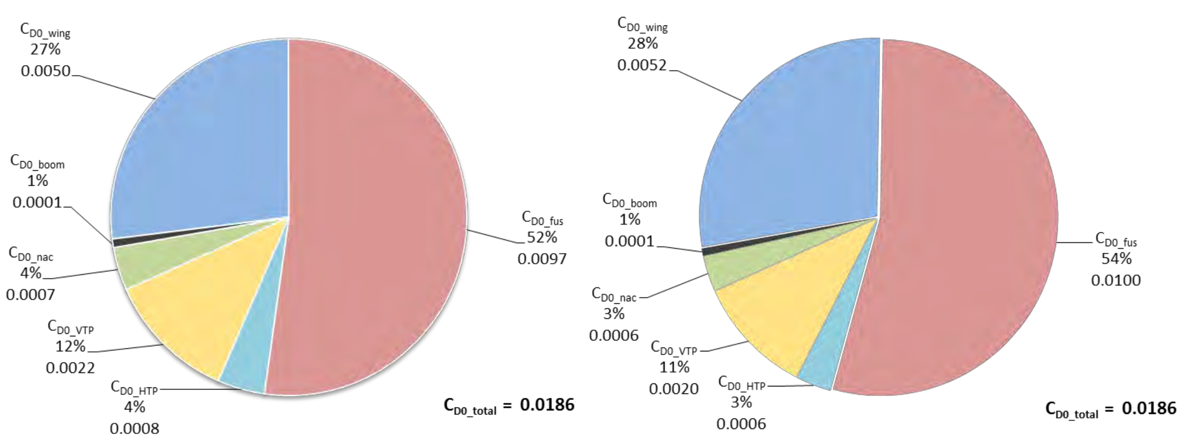


Figure 5-1: Parasite Drag Build-Up for StratoKiwi (left) and StratoDodo (right) in Cruise Condition

In estimating parasite drag, both wing, HTP, and VTP was treated as a lifting surface, and thus, its drag will include skin-friction drag and wave drag. Fuselage, engine nacelle, and empennage tip boom was treated as non-lifting surfaces and its wave drag was not taken into account as the aircrafts will cruise below Mach number of 1.0. Other than that, landing gear and flap was treated as a special body with its own computation precodure. With this assumption, parasite drag was estimated for various flight condition and its built-up in cruise condition was shown in Figure 5-1 while its estimation values for various flight conditions are summarized in the following Table 5-1 and Table 5-2.

In estimating lift-induced drag, induced drag factor (k) was estimated as a function of wing aspect ratio and Oswald span efficiency ratio. The Oswald span efficiency factor was calculated using the equation (12.49) in Raymer[11] and this led to induced drag factor of 0.0414 for StratoKiwi and 0.0442 for StratoDodo. Note that induced drag factor is not a function of flight condition and it is only affected by flap configuration. The value of induced drag factor for various flap configuration was summarized in Table 5-1 and Table 5-2.

Table 5-1: Drag Polar Table for StratoKiwi

<table>
<tr><th rowspan="2">Configuration</th><th rowspan="2">Mach</th><th colspan="2">FL450</th><th colspan="2">FL250</th><th colspan="2">Sea Level</th></tr>
<tr><th>$C_{D,0}$</th><th>K</th><th>$C_{D,0}$</th><th>K</th><th>$C_{D,0}$</th><th>K</th></tr>
<tr><td rowspan="9">Clean Configuration</td><td>0.2</td><td>0.0215</td><td rowspan="9">0.0414</td><td>0.0187</td><td rowspan="9">0.0414</td><td>0.0157</td><td rowspan="9">0.0414</td></tr>
<tr><td>0.3</td><td>0.0203</td><td>0.0175</td><td>0.0151</td></tr>
<tr><td>0.4</td><td>0.0195</td><td>0.0169</td><td>0.0147</td></tr>
<tr><td>0.5</td><td>0.0189</td><td>0.0165</td><td>0.0143</td></tr>
<tr><td>0.6</td><td>0.0184</td><td>0.0160</td><td>0.0139</td></tr>
<tr><td>0.7</td><td>0.0180</td><td>0.0158</td><td>0.0137</td></tr>
<tr><td>0.8</td><td>0.0186</td><td>0.0161</td><td>0.0143</td></tr>
<tr><td>0.85</td><td>0.0231</td><td>0.0205</td><td>0.0184</td></tr>
<tr><td>0.9</td><td>0.0384</td><td>0.0369</td><td>0.0339</td></tr>
<tr><td>Take-Off Flap Configuration (L/G Retracted)</td><td>0.2</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0.0624</td><td>0.0444</td></tr>
<tr><td>Take-Off Flap Configuration (L/G Extended)</td><td>0.2</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0.1007</td><td>0.0444</td></tr>
<tr><td>Landing Flap Configuration (L/G Retracted)</td><td>0.2</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0.2178</td><td>0.0478</td></tr>
<tr><td>Landing Flap Configuration (L/G Extended)</td><td>0.2</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0.2560</td><td>0.0478</td></tr>
</table>

Table 5-2: Drag Polar Table for StratoDodo

Configuration	Mach	FL450		FL250		Sea Level	
		$C_{D,0}$	K	$C_{D,0}$	K	$C_{D,0}$	K
Clean	0.2	0.0220	0.0442	0.0184	0.0442	0.0159	0.0442
	0.3	0.0210		0.0175		0.0154	
	0.4	0.0197		0.0171		0.0149	
	0.5	0.0192		0.0166		0.0146	
	0.6	0.0186		0.0160		0.0143	
	0.7	0.0184		0.0156		0.0140	
	0.8	0.0186		0.0159		0.0144	
	0.85	0.0226		0.0199		0.0184	
	0.9	0.0393		0.0363		0.0337	
Take-Off Flap Configuration (L/G Retracted)	0.2	-	-	-	-	0.0627	0.0476
Take-Off Flap Configuration (L/G Extended)	0.2	-	-	-	-	0.0951	0.0476
Landing Flap Configuration (L/G Retracted)	0.2	-	-	-	-	0.1948	0.0515
Landing Flap Configuration (L/G Extended)	0.2	-	-	-	-	0.2271	0.0515

With the parasite drag and lift-induced drag at all flight conditions known, drag polar for cruise condition was generated as shown in Figure 5-2. The plots show that the maximum lift-over-drag for StratoKiwi and StratoDodo is 18.02 and 17.45. However, this lift-over-drag value is achieved at C_L value of 0.67 for StratoKiwi and 0.65 for StratoDodo, not at cruise C_L value. By assuming cruise weight of $MTOW - 0.4 \times W_{F,max}$ as suggested by Roskam, it was found that the cruise C_L for StratoKiwi and StratoDodo are 0.2448 and 0.2571. At this C_L value, lift-to-drag ratio for both aircrafts are 11.62 and 11.97 and these values were higher than the assumed cruise lift-to-drag ratio assumed for cruise in the initial weight sizing (section 3.2), which is only 11.26. However, with the SFC found to be 0.73 from the engine characteristics done in section 4.1, higher lift-to-drag ratio of 12.6 is now necessary in order to achieve the mission cruise range. Both aircrafts fell short in this matter, however, Kentfield[8] suggested that OHVS configuration could increase the lift-to-drag ratio by 30%-35% compared to the conventional aircraft configuration. In order to be conservative, 10% increase in lift-to-drag was assumed and this leads to cruise lift-to-drag ratio of 12.78

and 13.17, which is higher than the required 12.6. Note this 10% increase of lift-to-drag ratio was not taken into account when estimation the aircraft performances. Instead, it will be shown in the following performance analysis that this shortcoming in lift-over-drag was compensated by other factor such as lighter aircraft weight.

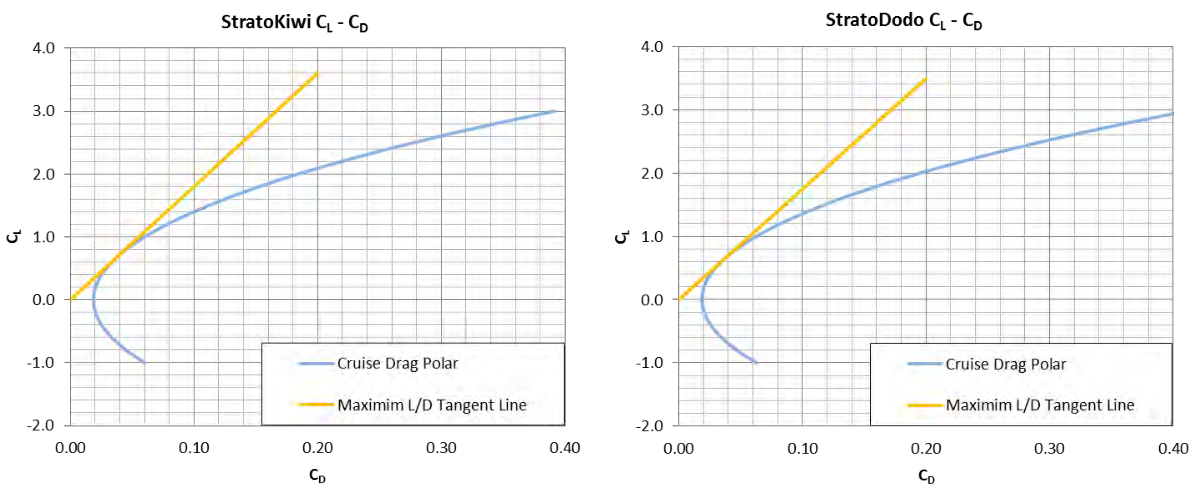


Figure 5-2: Drag Polar in Cruise Condition for StratoKiwi (left) and StratoDodo (right)

5.2. Estimation of Lift Polar

Estimation of lift polar is done to ensure that the aircraft can generate sufficient lift to counteract its weight. Similar to the estimation of drag polar outlined in the previous section, while its requirement is not explicitly stated in the DRO, it is essential in ensuring several items in the DRO is achievable, especially for BFL and landing field length requirement. For StratoKiwi and StratoDodo, the estimation of lift polar was done mainly by following class II lift estimation proposed by Roskam[18]. However, since HTP is placed outboard of the wing, it experienced upwash instead of downwash. Thus, to accommodate this configuration, downwash gradient term in class II lift estimation proposed by Roskam[18] was replaced with the upwash gradient term that was formulated by Sleeman[21]. With this modified class II estimation method, the aircrafts' lift polar were obtained and shown in the following Figure 5-3 while its results are summarized in Table 5-3 below.

Table 5-3: Lift Polar Characteristic for Various Flap Configuration

Aircraft Lift Curve Parameter				StratoKiwi	StratoDodo
Clean Configuration	$\partial C_L/\partial\alpha$	Lift Slope	[deg^{-1}]	0.1838	0.1797
	$C_{L,max}$	Maximum Lift Coefficient	[-]	1.9946	1.9856
	α_0	Zero Lift Angle-of-Attack	[deg]	-4.2623	-4.2541
	$C_{L,0}$	Lift Coefficient at Zero Angle-of-Attack	[-]	0.0137	0.0133
Take-Off Flap Comfiguration	$(\partial C_L/\partial\alpha)_\delta$	Lift Slope	[deg^{-1}]	0.1924	0.1869
	$\Delta C_{L,max,TO}$	Lift Increment	[-]	0.2927	0.2569
Landing Flap Configuration	$(\partial C_L/\partial\alpha)_\delta$	Lift Slope	[deg^{-1}]	0.2304	0.2193
	$\Delta C_{L,max,Land}$	Lift Increment	[-]	0.6003	0.5176

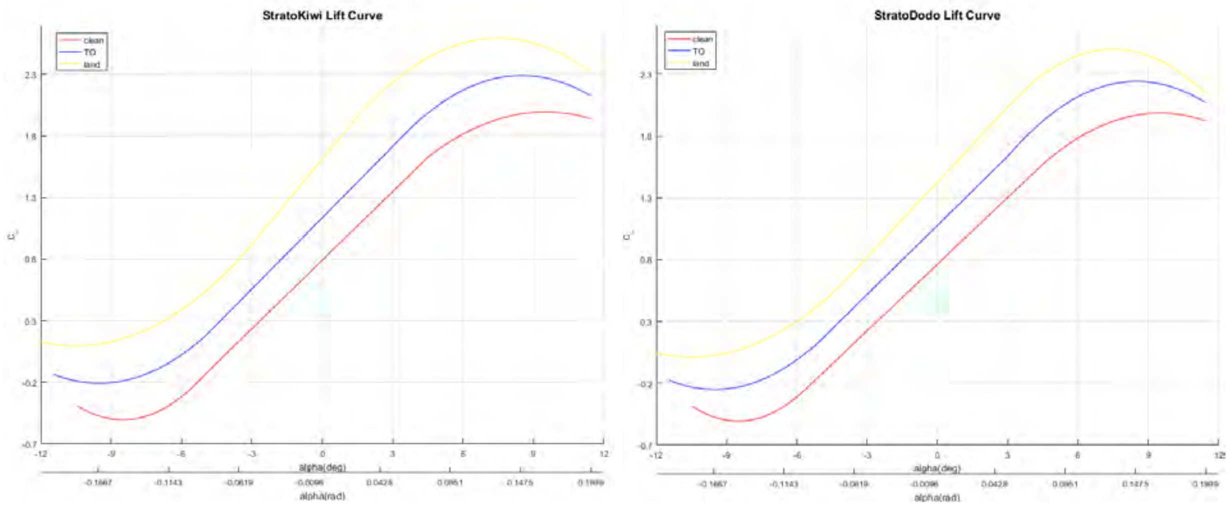


Figure 5-3: Lift Polar for StratoKiwi (left) and StratoDodo (right)

While it was not used for any performance related analysis, it was necessary to compute the spanwise distribution of lift as it might be needed for structural sizing and stress estimation. Based on take-off wing loading values selected in the matching chart, the lift distribution per unit span length was calculated with Schrenk's method and the results are shown in Figure 5-4 below.

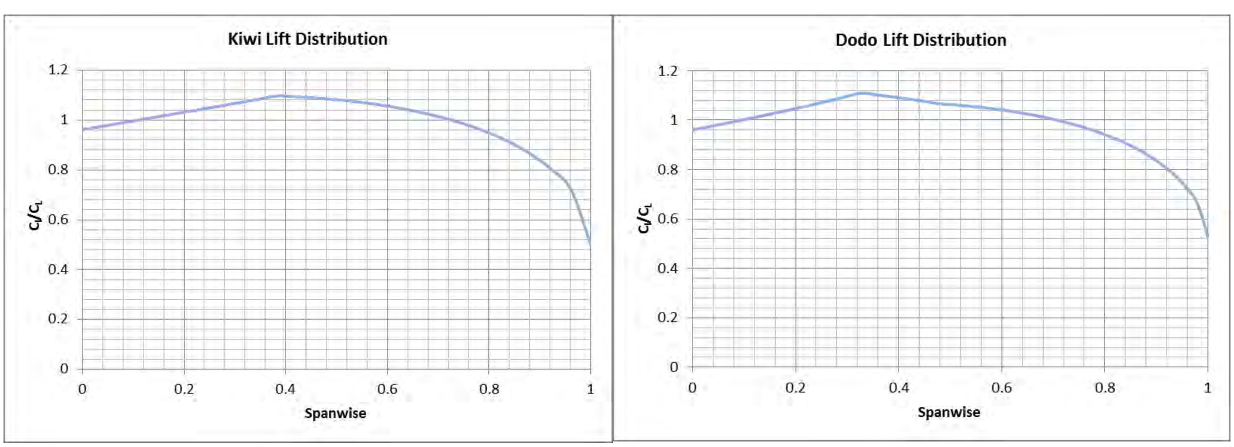


Figure 5-4: Spanwise Lift Distributino for StratoKiwi (left) and StratoDodo (right)

5.3. Flight Envelope Estimation

Flight envelope estimation is done to provide general overview of an aircraft's capability to sustain a steady flight at a certain altitude and airspeed in order to ensure rate-of-climb requirement and maximum speed requirement stated in the DRO are satisfied. Flight envelope is affected by the aircraft's propulsion system capability and its drag polar and it can be easily determined by calculating the aircraft's excess power in every combination of flight altitude and Mach number and applying several flight limitations, such as stall speed limitation, maximum operating speed limitation (VMO), and maximum operating Mach number (MMO) limitation. For StratoKiwi and StratoDodo, its flight envelopes were determined by estimating the aircraft's drag in a level flight and available thrust at every combination of flight altitude and Mach number. The drag was estimated based on the drag polar obtained in section 5.1 while the available thrust was estimated based on performance estimation outlined in section 4.1. As for the flight limitation, maximum dynamic pressure of 20,000 Pa was applied as VMO limit. This value was chosen based on the need to push through Mach 0.85 at 35000 ft. At said high speed cruise condition, dynamic pressure was estimated to be around 16000 Pa and thus, it was decided to set the maximum dynamic pressure for VMO limitation with 25% margin from this value. On the other hand, Mach number of 0.9 was applied as MMO limit, which is a typical limitation for high bypass turbofan engine.

With the drag and available thrust computed, the excess power was obtained then converted into rate-of-climb and plotted with all the limitations applied to generate the flight envelope. Note that while it is practically impossible to keep flying at MTOW due to fuel burn, in order to be conservative, flight envelopes for StratoKiwi and StratoDodo were computed for MTOW and the resulting plots are shown by the following Figure 5-5 and Figure 5-6. From these flight envelope, compliance from several items on DRO can be easily identified and it is presented in Table 5-4 below for convenience.

Table 5-4: DRO Compliance from Flight Envelope Estimation

DRO		StratoKiwi	StratoDodo
Rate of Climb in Clean Configuration with Maximum Take-Off Power at Sea Level ISA Condition	1067 m/min (3500 ft/min)	1775 m/min (5823 ft/min)	1344 m/min (4409 ft/min)
Rate of Climb in Clean Configuration at Cruise Ceiling (13716 m / 45000 ft)	91.4 m/min (300 ft/min)	565 m/min (1853 ft/min)	281 m/min (921 ft/min)
Rate of Climb in Clean Configuration at Service Ceiling (14326 m / 47000 ft)	30.4 m/min (100 ft/min)	455 m/min (1492 ft/min)	195 m/min (639 ft/min)
Maximum Cruise Speed at 10670 m / 35000 ft	Mach 0.85	Mach 0.89	Mach 0.87
Service Ceiling	14326 m (47000 ft)	17200 m (56430 ft)	15420 m (50500 ft)

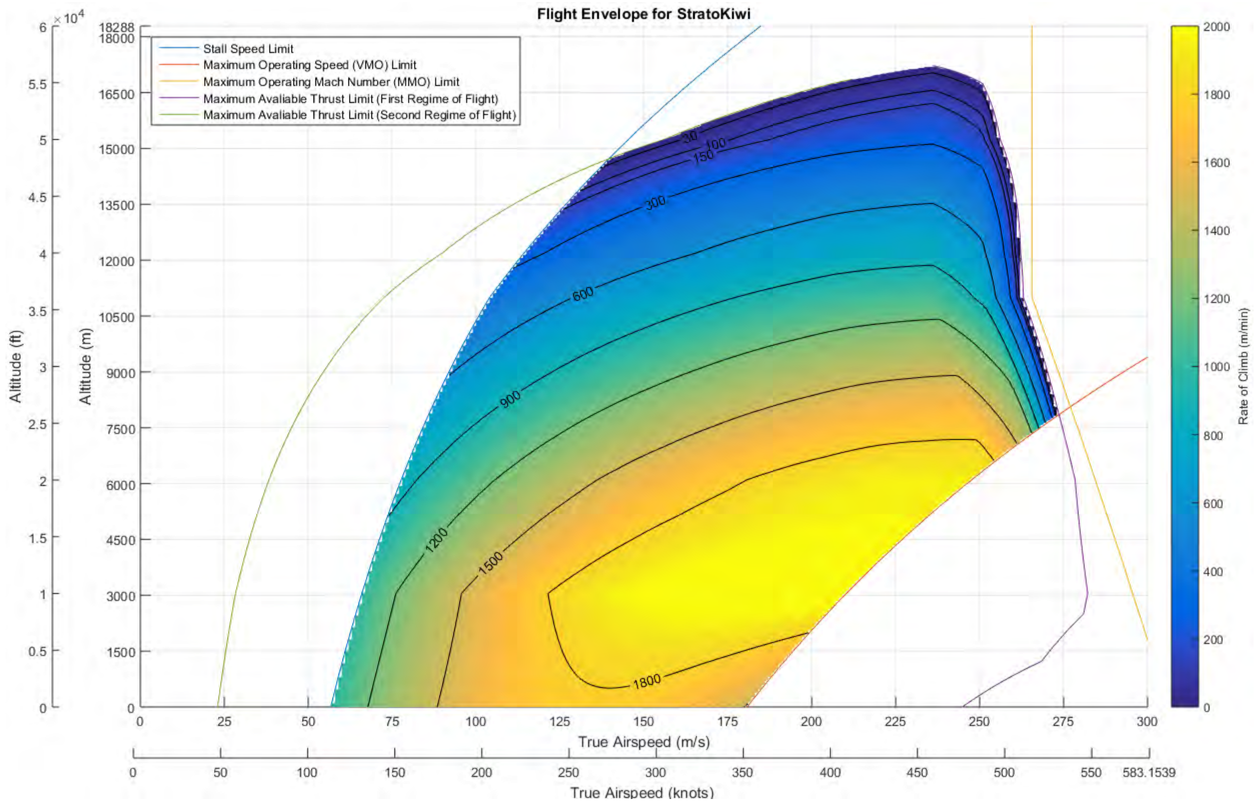


Figure 5-5: Flight Envelope for StratoKiwi at MTOW

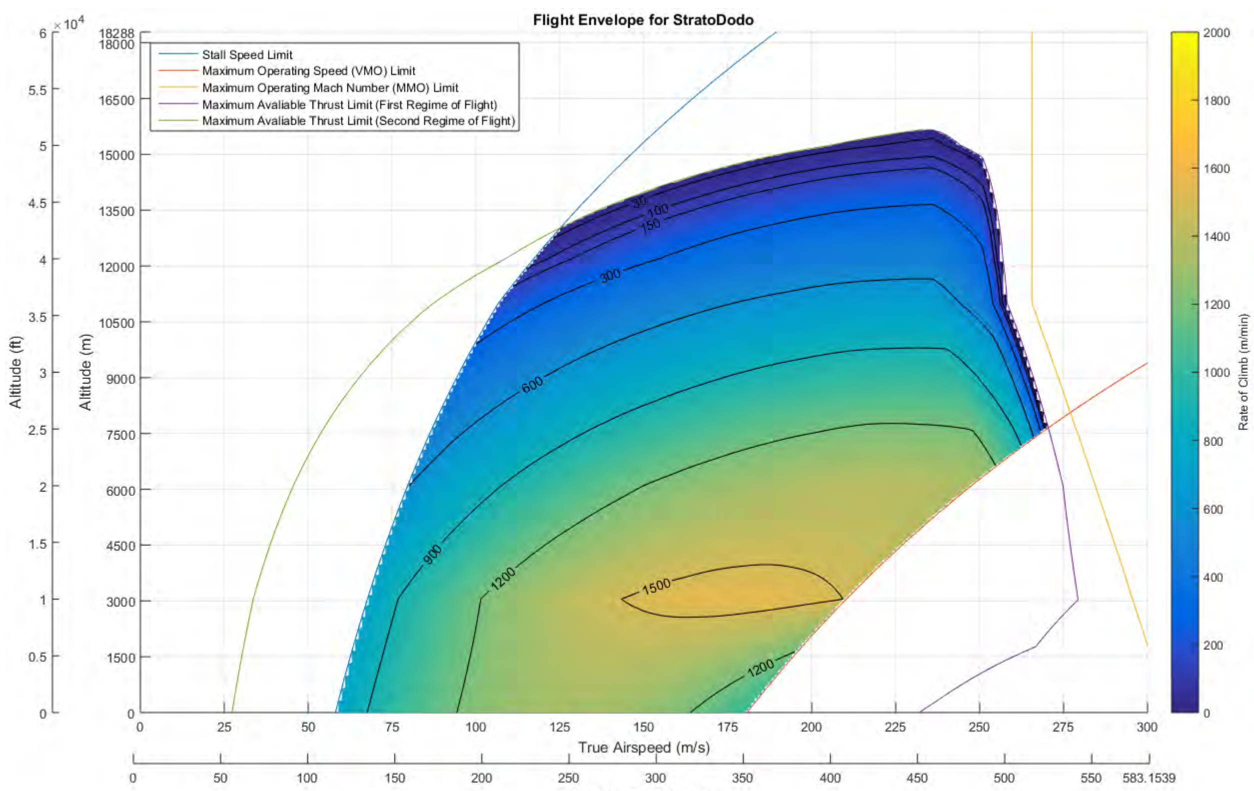


Figure 5-6: Flight Envelope for StratoDodo at MTOW

With the flight envelope known and maximum achievable cruise speed in every altitude found, V-n diagram for both StratoKiwi and StratoDodo were estimated for the need of structural analysis. Note that due to the difference in certification, V-n diagrams for StratoKiwi and StratoDodo was computed differently and with different model of gust speeds. The resulting V-n diagrams for both StratoKiwi and StratoDodo are presented in the following Figure 5-7 to Figure 5-12.

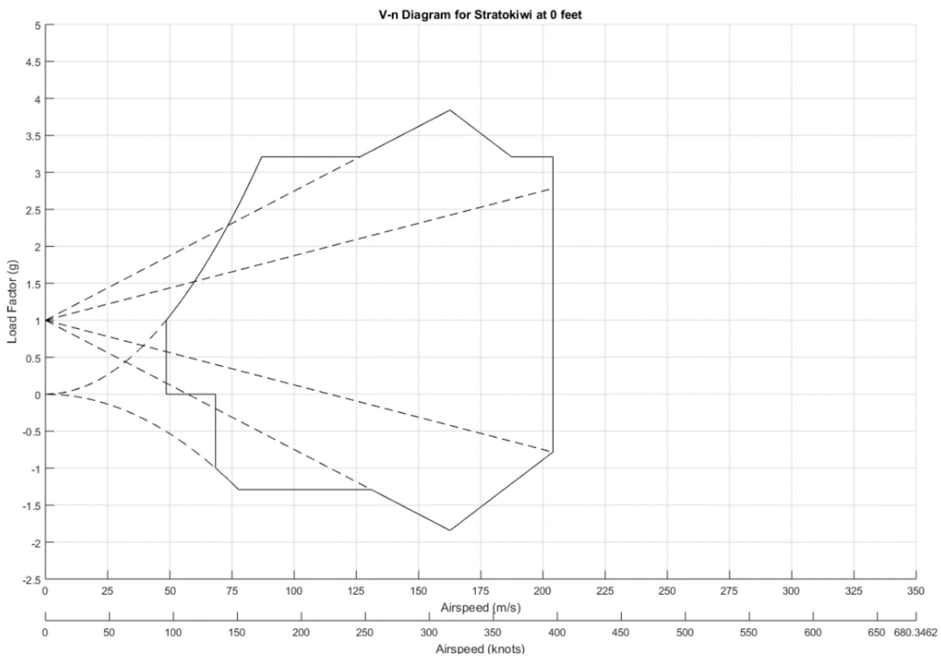


Figure 5-7: V-n Gust Diagram for StratoKiwi at Sea Level

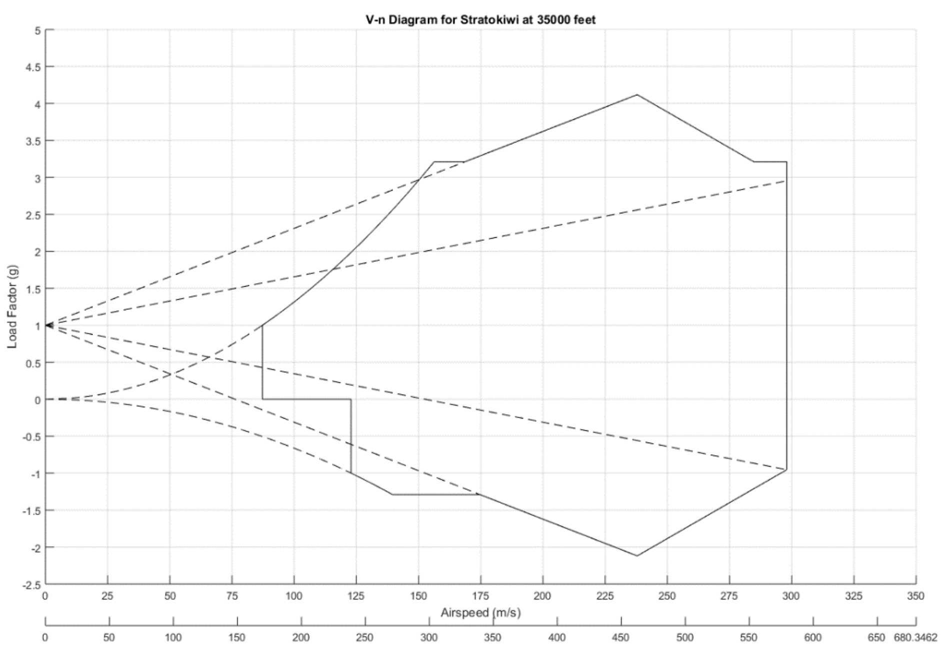


Figure 5-8: V-n Gust Diagram for StratoKiwi at 10668 m (35000 ft) Altitude

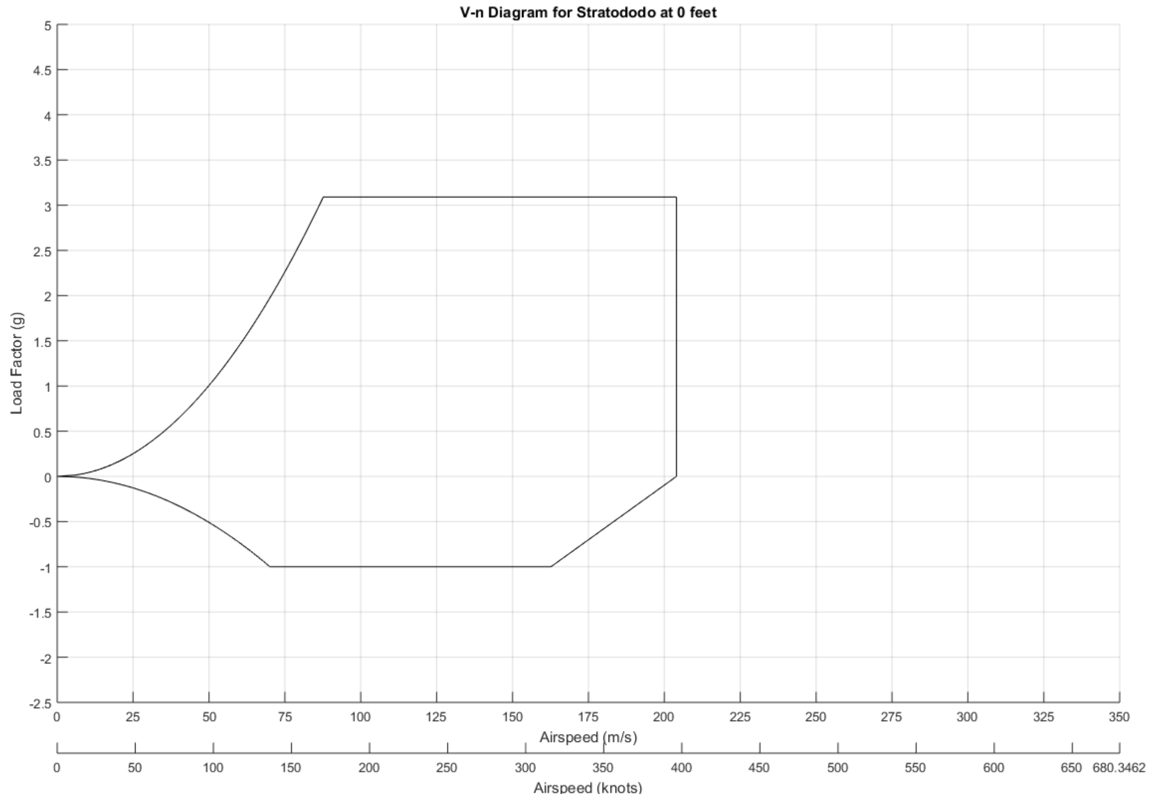


Figure 5-9: V-n Diagram for StratoDodo at Sea Level

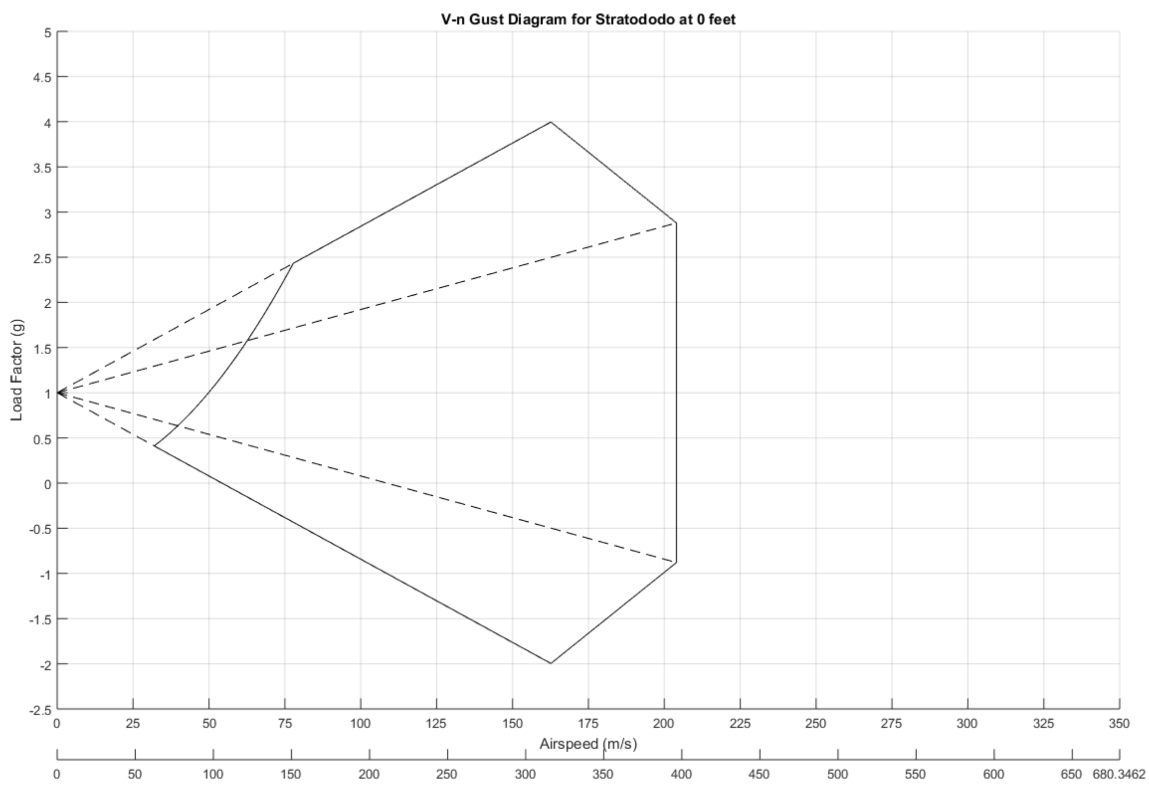


Figure 5-10: Gust Diagram for StratoDodo at Sea Level

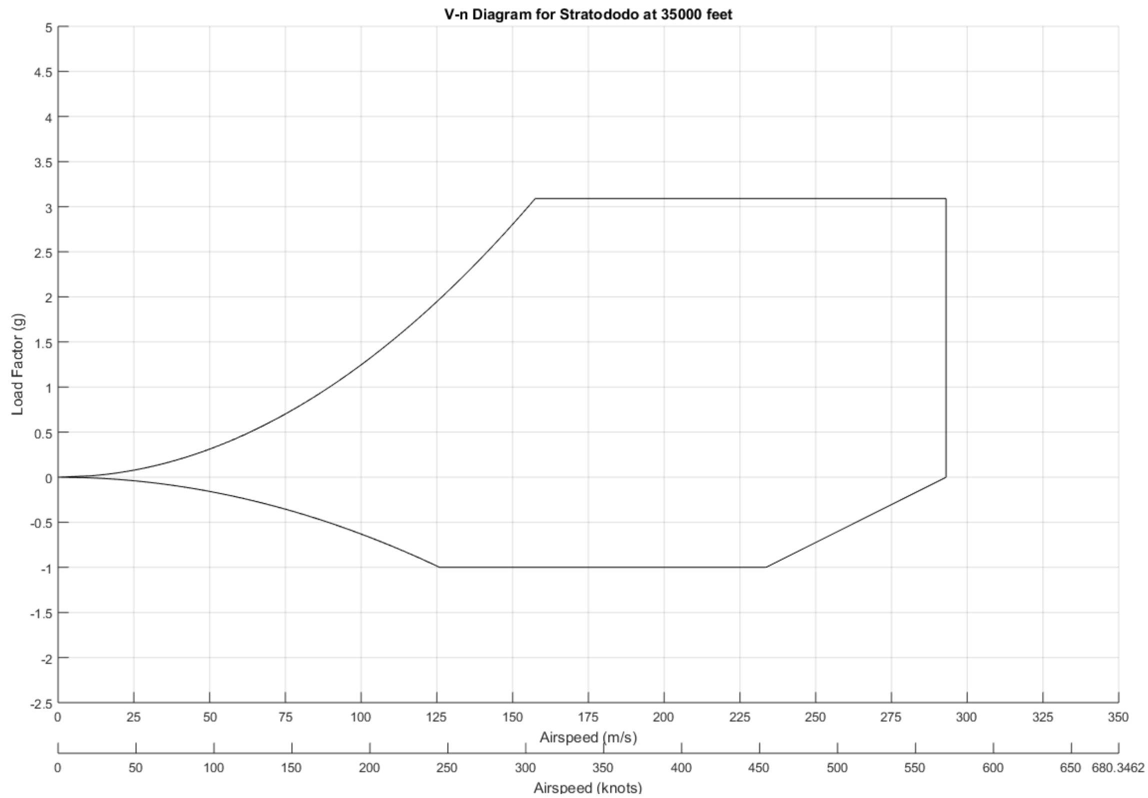


Figure 5-11: V-n Diagram for StratoDodo at 10668 m (35000 ft) Altitude

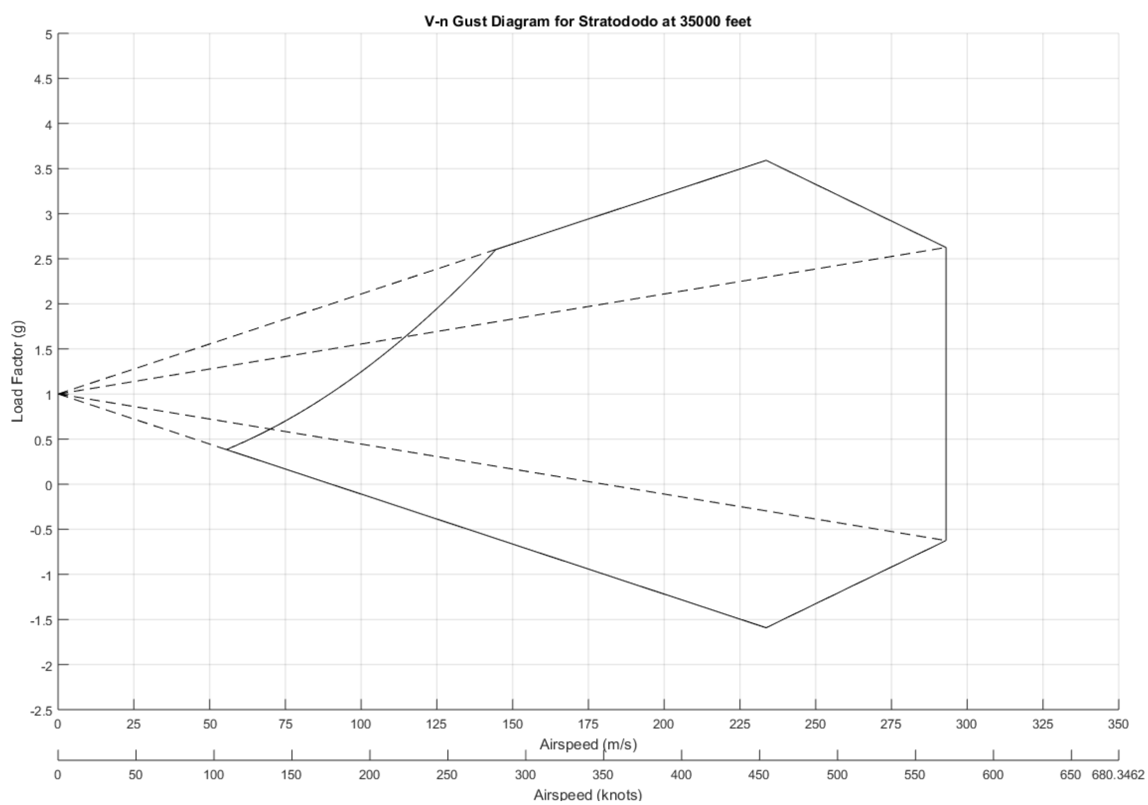


Figure 5-12: Gust Diagram for StratoDodo at 10668 m (35000 ft) Altitude

5.4. Cruise Performance Analysis

Cruise performance analysis is done to ensure the minimum cruise range requirement stated in the DRO are satisfied. This consists of two parts, estimating specific range to ensure that the cruise condition selected previously in section 2.1 is the most optimal condition and generating payload-range diagram to quantify both aircrafts cruise performance quality.

5.4.1. Specific Range Diagram

Specific range diagram expresses an aircraft's instantaneous cruise performance at a certain weight and cruise condition. Since specific range is instantaneous, in practical, it will change throughout the cruise as the aircraft becomes lighter due to fuel burn. Nevertheless, it can be used to find the optimal cruise condition at a certain point of flight in order to maximize the total cruise range. For StratoKiwi and StratoDodo, its specific range was estimated by using equation (5-1) below with lift-to-drag ratio coming from drag polar estimation outlined in section 5.1 and SFC value coming from engine performance estimation outlined in section 4.1. For each aircraft, specific range diagrams for both constant cruise altitude and constant cruise Mach number were generated and the results are presented in the following Figure 5-13, Figure 5-14, Figure 5-15, and Figure 5-16.

$$SR = \frac{V}{SFC \times \frac{1}{LoD} \times W}$$

(5-1)

Specific range diagrams for constant cruise Mach number (Figure 5-13 and Figure 5-15) show maximum specific range is achieved at higher altitude of 15545 m (51000 ft). This was different with the determination of optimal cruise condition outlined early in section 2.1, however, it was expected as the determination of optimal cruise condition done in the early phase of this project did not cover higher altitude due to the lack of data. Nevertheless, it should also be kept in mind that cruising at this altitude is not possible for StratoDodo due to cruise ceiling rate-of-climb requirement. On the other hand, Specific range diagrams for constant cruise Mach number (Figure 5-14 and Figure 5-16) shows that maximum specific range is achieved at Mach number of 0.8, which is in agreement with the results of determination of optimal cruise condition. However, as the aircraft gets lighter, the optimal cruise condition shifted to lower Mach number due to the need to stay at the optimal lift coefficient for maximum lift-to-drag ratio. Note that regardless of the finding that more specific range can be gained at higher cruise altitude, it was decided to keep the altitude of 13716 m (45000 ft) as the optimal cruise altitude for StratoKiwi and StratoDodo.

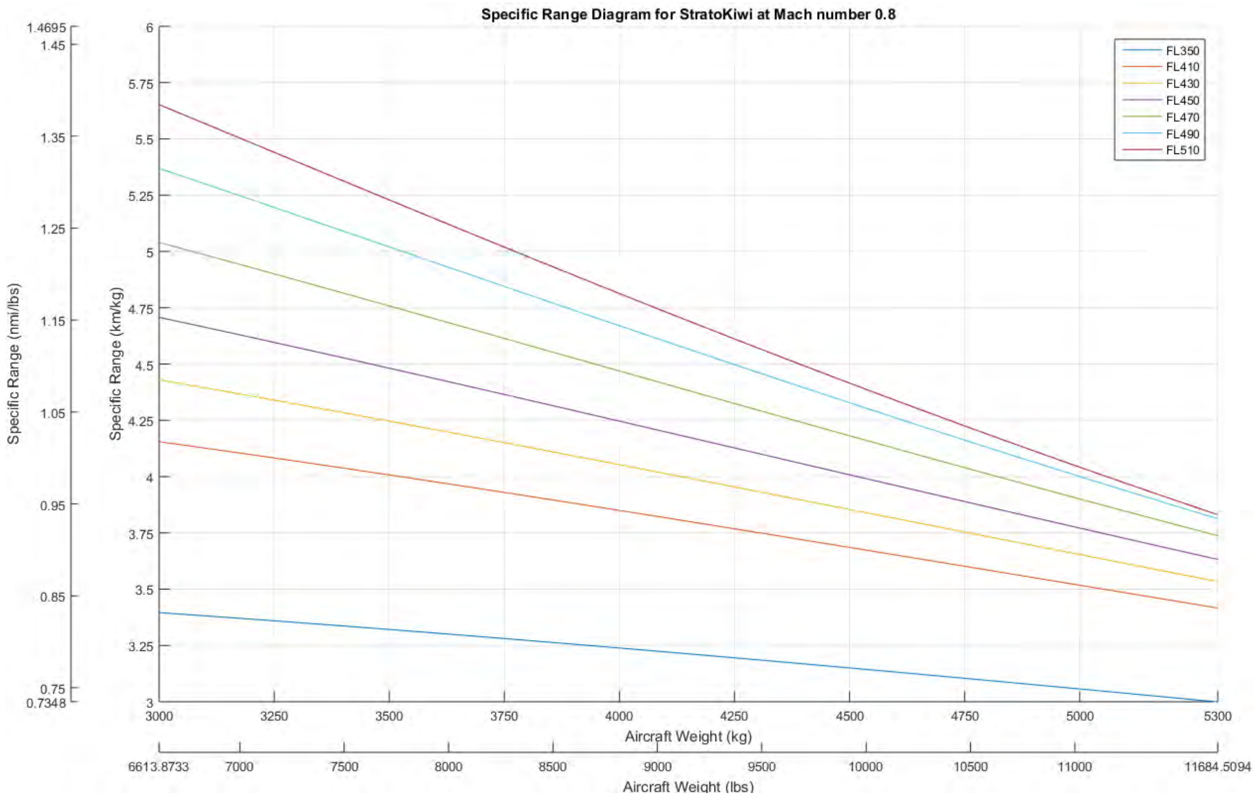


Figure 5-13: Specific Range Diagram for StratoKiwi at Cruise Mach Number of 0.8

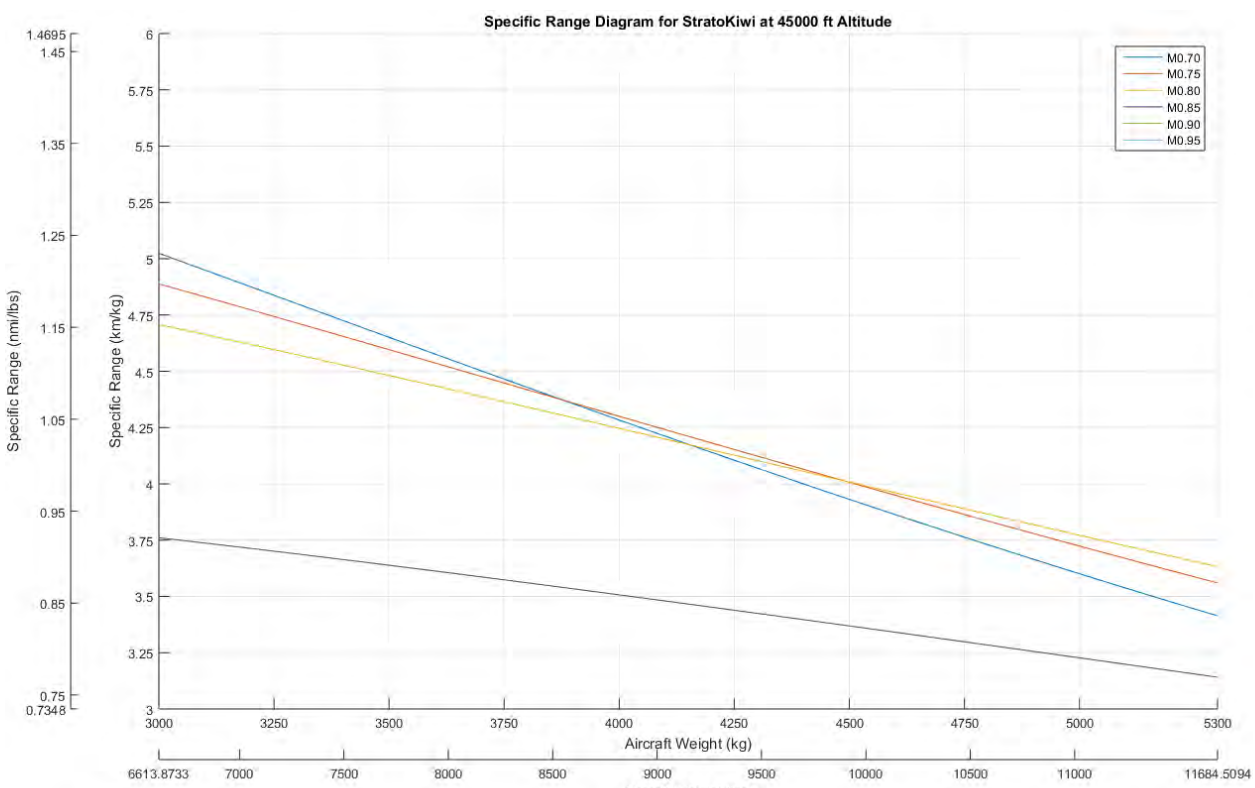


Figure 5-14: Specific Range Diagram for StratoKiwi at 14764 m (45000 ft) Cruise Altitude

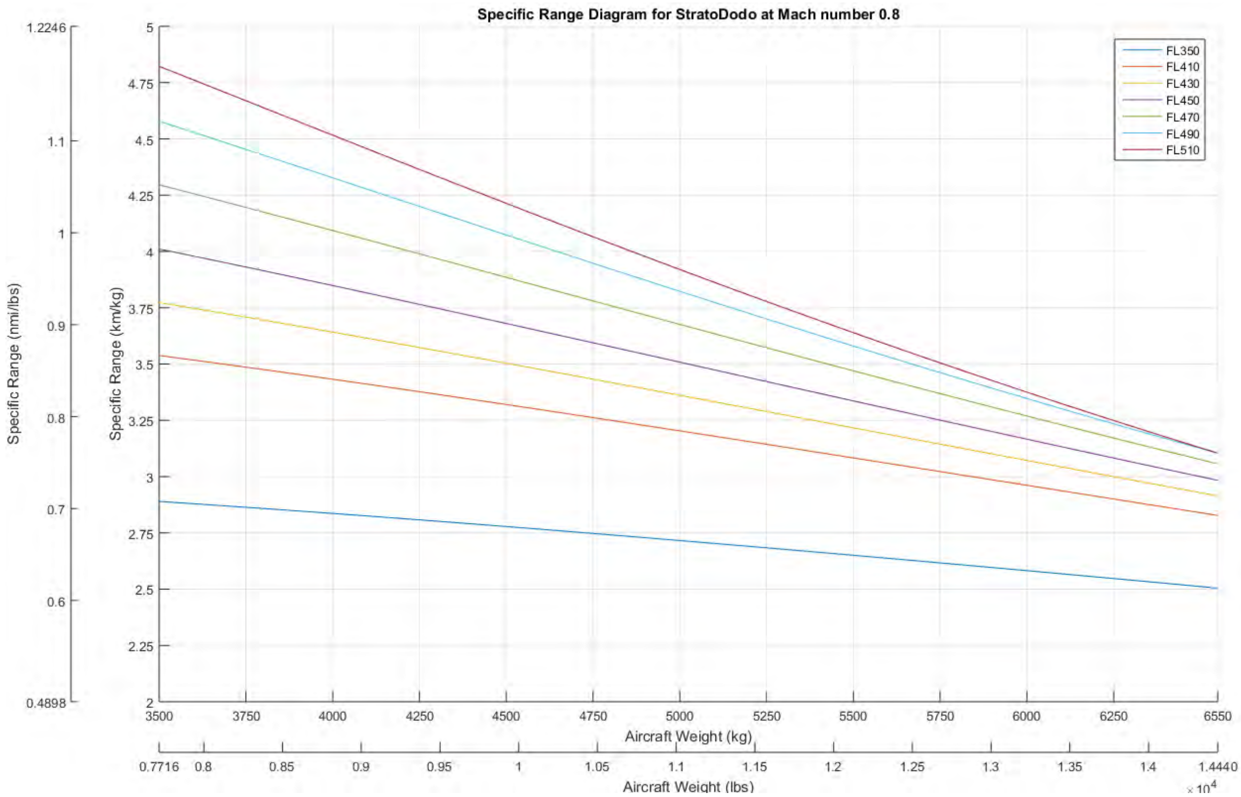


Figure 5-15: Specific Range Diagram for StratoDodo at Cruise Mach Number of 0.8

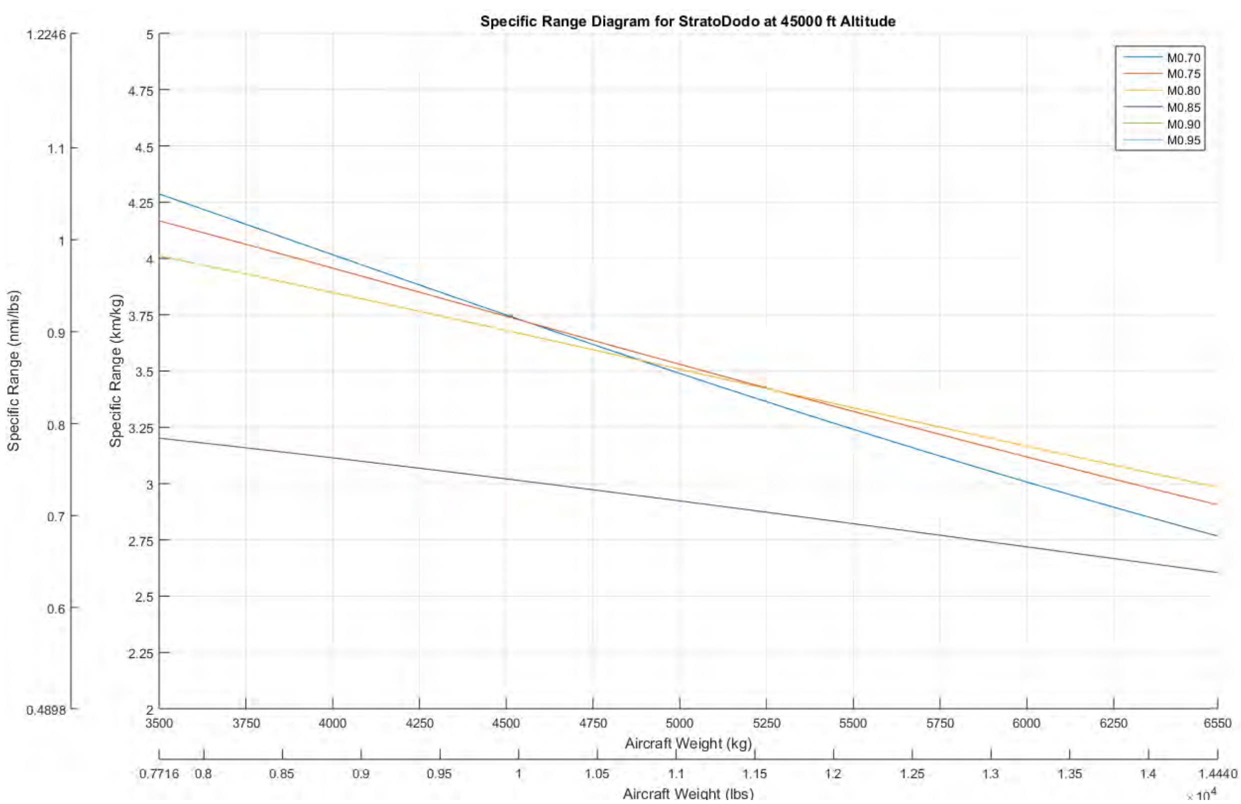


Figure 5-16: Specific Range Diagram for StratoDodo at 14764 m (45000 ft) Cruise Altitude

5.4.2. Payload-Range Diagram

To further estimate the cruise performance of StratoKiwi and StratoDodo, payload-range diagrams were generated as a means of evaluation. In generating this diagrams, Breguet range equation was used along the drag polar outlined in section 5.1. To simplify the range calculation, cruise lift coefficient was also assumed to be constant at lift coefficient value for level flight in the optimal cruise condition with aircraft weight of $MTOW - 0.4 \times W_{F,max}$. The resulting payload-range diagrams are presented in the following Figure 5-17 and Figure 5-18 and the results show that both StratoKiwi and StratoDodo is capable of achieving cruise range of 4630 km (2500 nmi) under nominal payload stated in the DRO. The important range parameters obtained from these diagram is also summarized in Table 5-5 below.

Table 5-5: Range Characteristic of StratoKiwi and StratoDodo

	StratoKiwi	StratoDodo
Maximum Payload Range	2433 km (1313 nmi)	2181 km (1177 nmi)
Nominal Range	4703 km (2539 nmi)	4701 km (2538 nmi)
Ferry Range	5005 km (2702 nmi)	5205 km (2810 nmi)

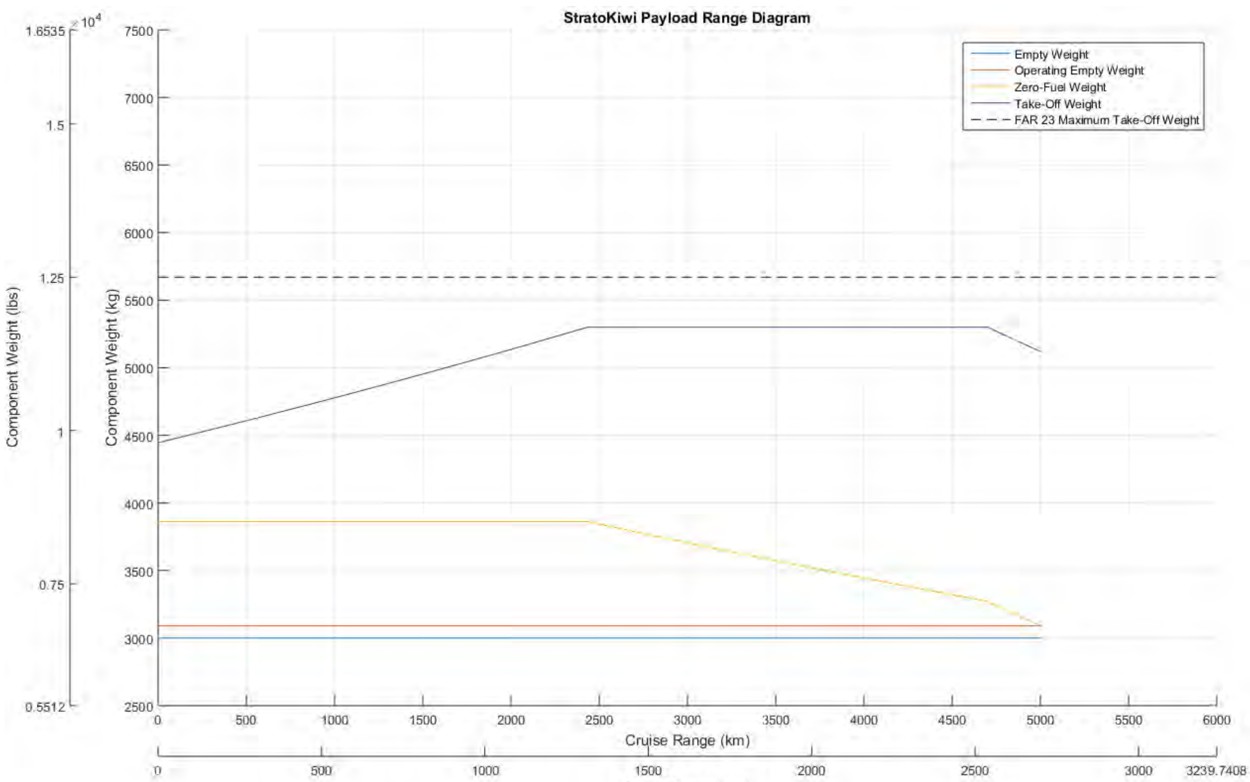


Figure 5-17: Payload-Range Diagram for StratoKiwi

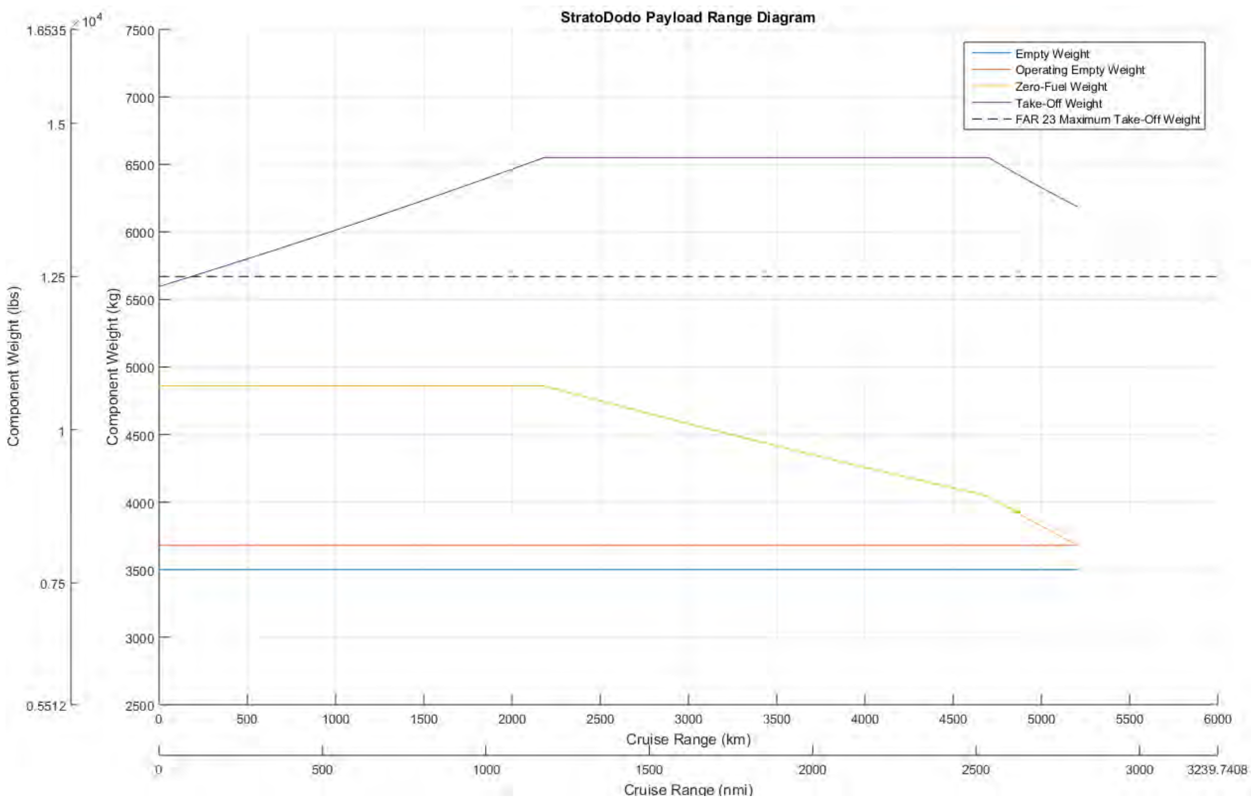


Figure 5-18: Payload-Range Diagram for StratoDodo

5.5. Ground Performance Analysis

5.5.1. Take-Off Performance Analysis

Take-off performance analysis is done to estimate the BFL for both aircrafts and ensure the BFL requirement stated in the DRO is satisfied. For StratoKiwi and StratoDodo, BFL was estimated by firstly determining the appropriate rotation speed (V_R) and minimum climb speed (V_2) that satisfy both FAR 25.107 and FAR 25.121. In doing so, minimum control speed (V_{MCA}) was also calculated based on C_{Y,δ_n} obtained from Roskam[18] and the relation between rotation speed and minimum climb speed was assumed to be proportional to thrust-to-weight ratio as shown in the following equation (5-2). After that, BFL was estimated by computing both OEI continued take-off distance (CTOD) and accelerate-to-stop distance (ASD) for any V_1 speed at MTOW and finding its intersection. Figure 5-19 and Figure 5-20 show the determination of rotation speed and minimum climb speed for StratoKiwi and StratoDodo respectively while Figure 5-21 and Figure 5-22 show the resulting plot for BFL determination.

$$V_2 - V_R = 15 \times T/W \tag{5-2}$$

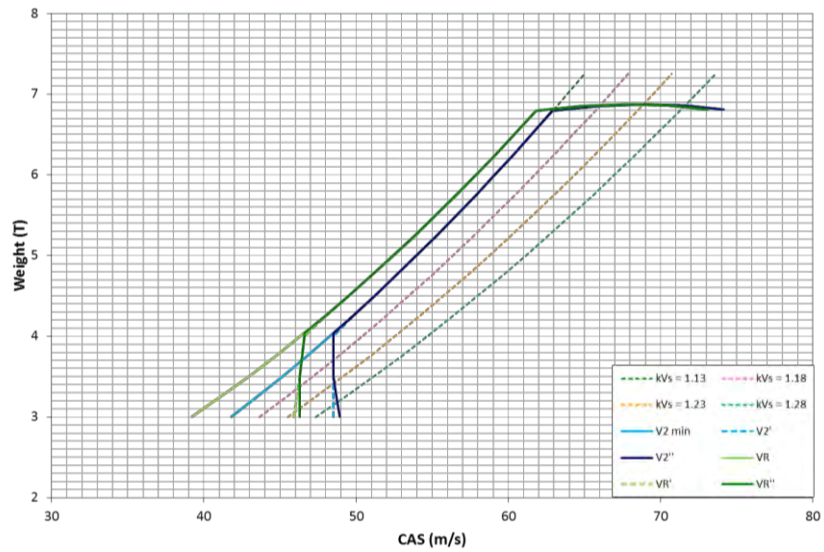


Figure 5-19: Rotation Speed (V_R) and OEI Minimum Climb Speed (V_2) for StratoKiwi

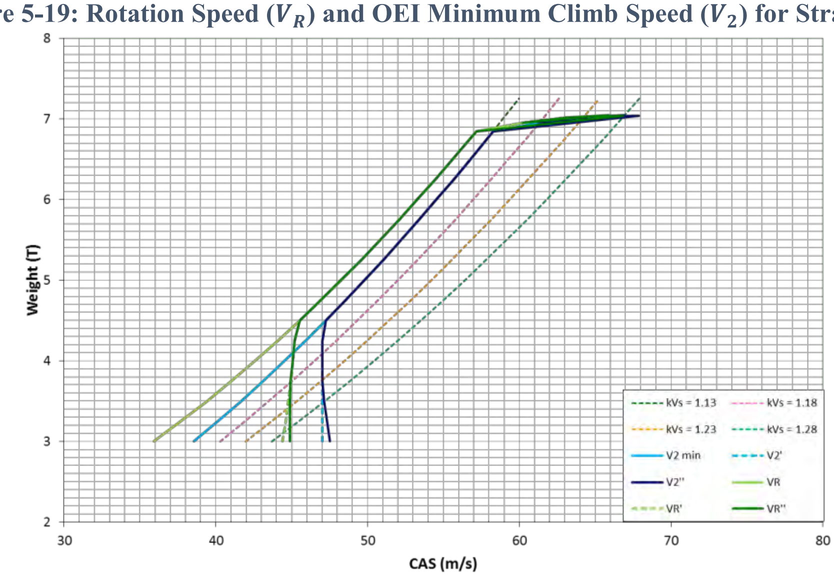


Figure 5-20: Rotation Speed (V_R) and OEI Minimum Climb Speed (V_2) for StratoDodo

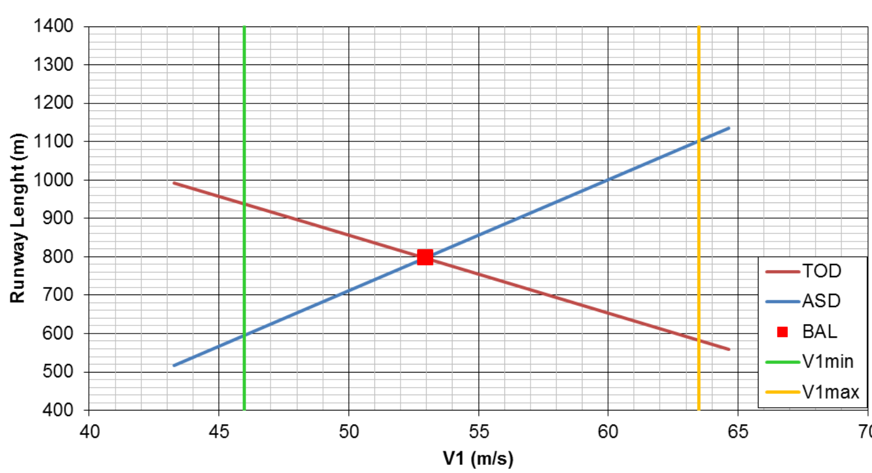


Figure 5-21: Determination of BFL for StratoKiwi

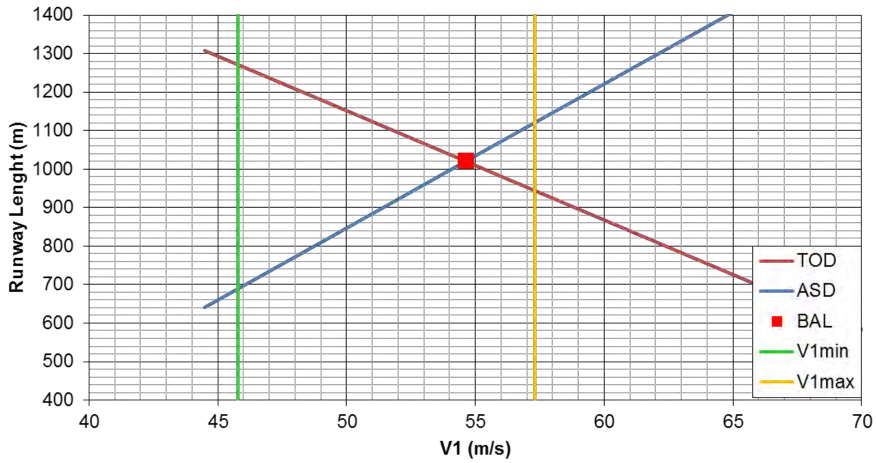


Figure 5-22: Determination of BFL for StratoDodo

From intersection of CTOD curve and ASD curve shown in Figure 5-21 and Figure 5-22, BFL was found to be 648 m (2126 ft) for StratoKiwi at MTOW and 900 m (2953 ft) at MTOW. With this result, compliance to DRO for BFL requirement is shown. Nevertheless, it should be also kept in mind that these BFL values were for V_1selection of 58 m/s (113.5 knots) for StratoKiwi and 57 m/s (111 knots) for StratoDodo.

5.5.2. Landing Performance Analysis

Landing performance analysis is done to estimate the maximum landing field length for both aircrafts and ensure the landing field length requirement stated in the DRO is satisfied. For StratoKiwi and StratoDodo, estimation of landing distance was done in a relatively straight forward manner using point mass kinematics with approach speed assumed to be $1.3 \times V_S$ as prescribed by both FAR 23 and FAR 25. Figure 5-23 shows the results of landing distance as a function of aircraft weight for both StratoKiwi and StratoDodo with the maximum allowable landing weight limited by the maximum braking energy. This allowable landing weight limit was found to be 4700 kg (10362 lbs) for StratoKiwi and 5000 k (11023 lbs), which is larger than the MLW value set up as design objective for the matching chart and design point selection summarized in Table 3-3. This means that both aircrafts are capable of performing landing at its designated MLW. At its own designated MLW (4000 kg for StratoKiwi and 4500 kg for StratoDodo), the landing field length was found to be 561 m (1840 ft) for StratoKiwi and 610 m (2001 ft) for StratoDodo, which is less then the landing field length requested by the DRO. With this result, the selection of MLW is justified and compliance to DRO for landing field length requirement is shown.

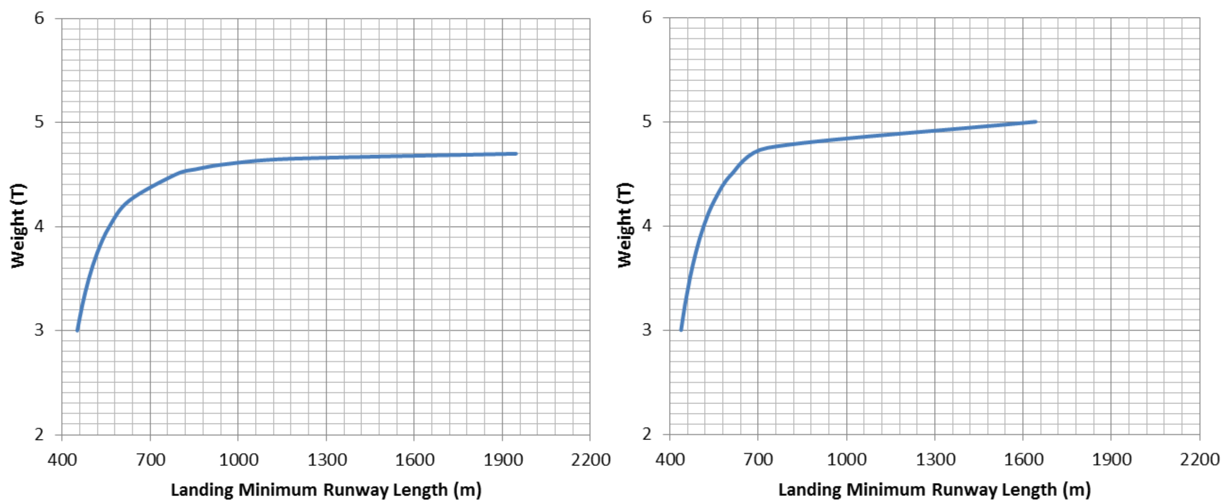


Figure 5-23: Minimum Landing Field Length for StratoKiwi (left) and StratoDodo (right)

5.6. Static Stability Analysis

Static stability analysis is done to ensure the aircraft's static stability in any flight condition. For StratoKiwi and StratoDodo, this was done by using DATCOM software. For this, *for005.dat* files that represent the configuration of both aircrafts were written and then processed with DATCOM's batch file. However, since StratoKiwi and StratoDodo features OHVS configuration that is considered unconventional, a workaround was implemented to represent the OHVS configuration. The OVS was represented as twin vertical tail panel using TVTPAN namecard while the OHS was represented as conventional HTP placed at the same longitudinal location but vertically far away from the aircraft's fuselage. This was done in order to avoid downwash effect from the wing on the HTP while preserving the same longitudinal moment arm length. Due to DATCOM's limitation to compute transonic cases, static stability computation was done only up to Mach number of 0.6. This was considered sufficient as an aircraft relatively become more stable as the Mach number increase.

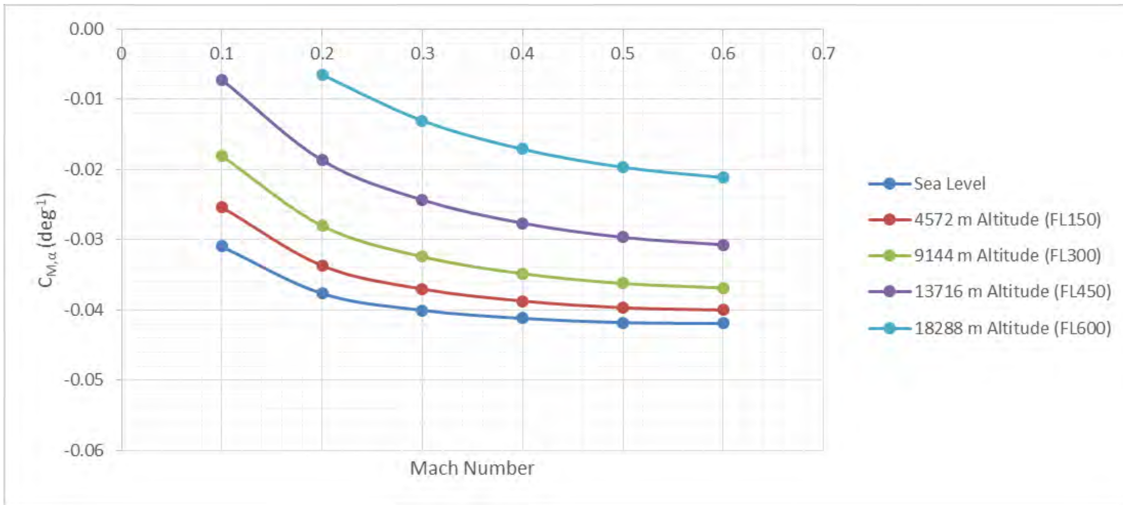


Figure 5-24: Longitudinal Static Stability Derivatives of StratoKiwi at Various Flight Conditions

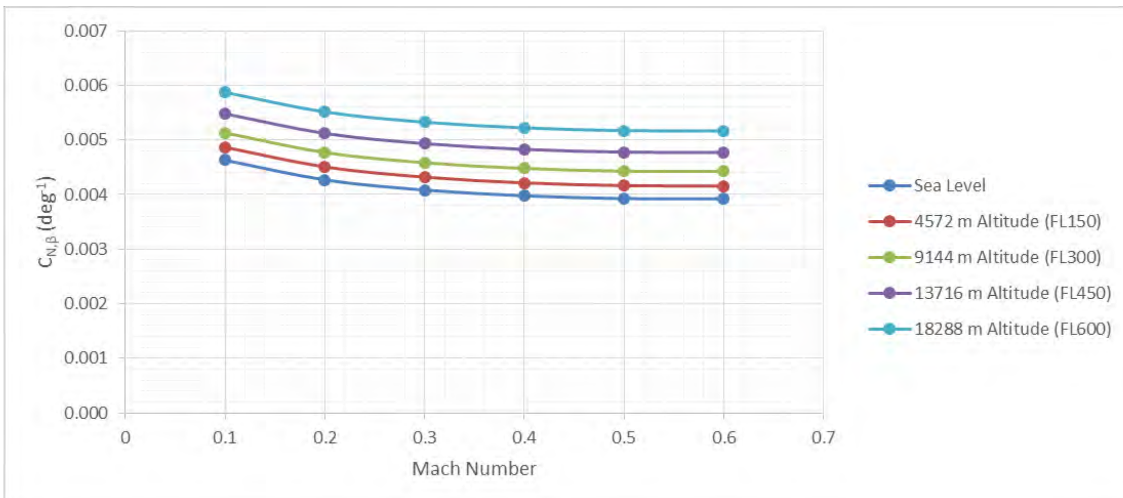


Figure 5-25: Directional Static Stability Derivatives of StratoKiwi at Various Flight Conditions

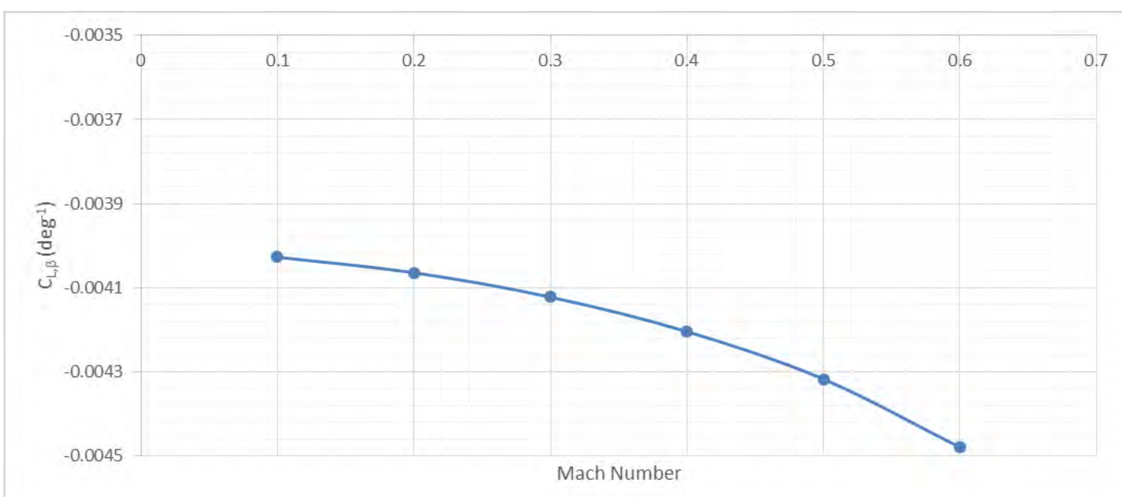


Figure 5-26: Lateral Static Stability Derivatives of StratoKiwi at Various Flight Conditions

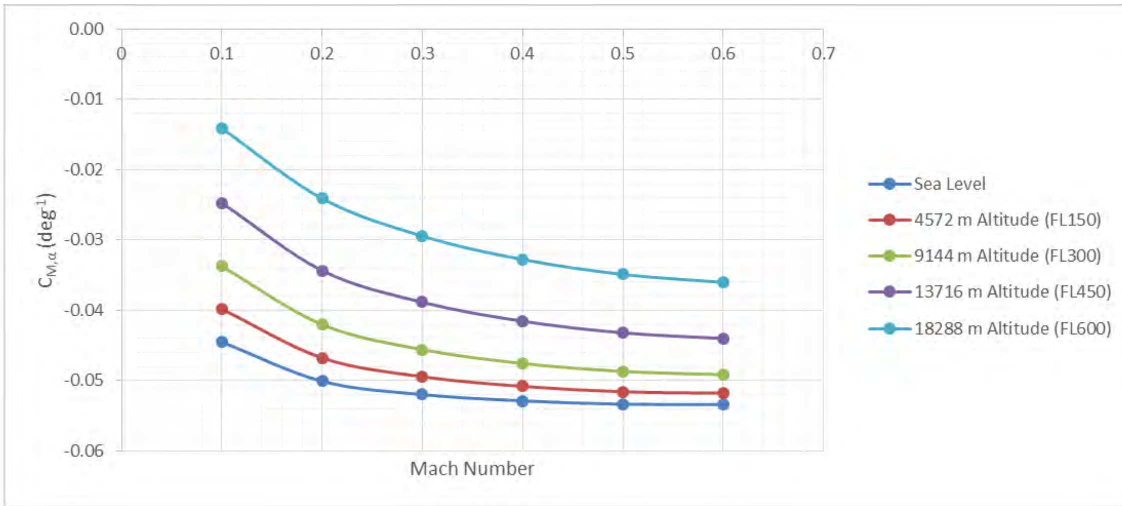


Figure 5-27: Longitudinal Static Stability Derivatives of StratoDodo at Various Flight Conditions

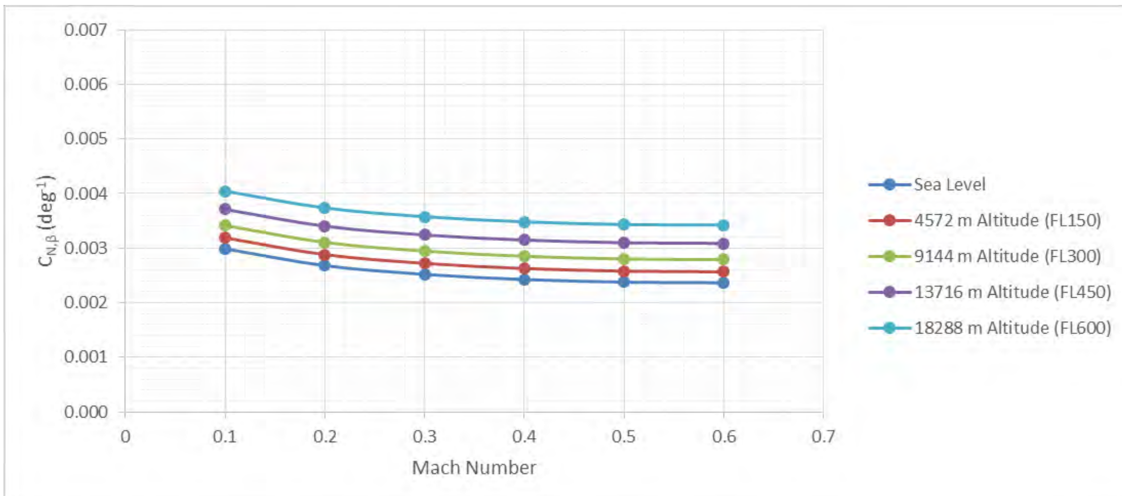


Figure 5-28: Directional Static Stability Derivatives of StratoDodo at Various Flight Conditions

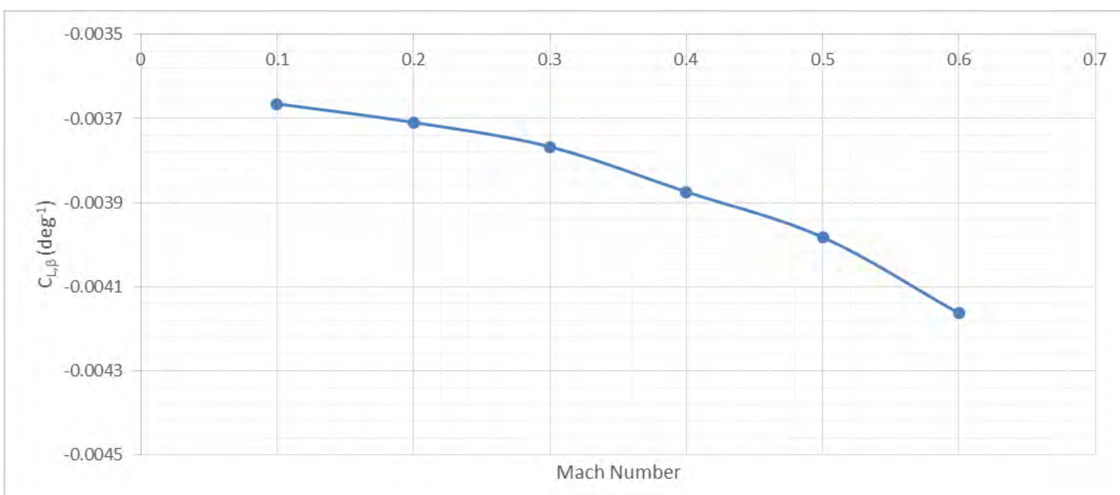


Figure 5-29: Lateral Static Stability Derivatives of StratoDodo at Various Mach Number

Figure 5-24, Figure 5-25, and Figure 5-26 show the static stability derivative computation results for StratoKiwi while Figure 5-27, Figure 5-28, Figure 5-29 show the static stability derivative computation results for StratoDodo. These plots show that StratoKiwi and StratoDodo was staticly stable in any flight conditions. These static stability derivates values were then compared with the historical data available in Gudmundsson[7]. For longitudinal static stability, StratoKiwi and StratoDodo were found to be too stable than its competitor aircrafts by the magnitude of two. For directional static stability, StratoKiwi and StratoDodo were found to be stable within the same magnitude compared to its competitor aircrafts. The $C_{N,\beta}$ values for both aircrafts were also found to be higher than 0.0013 which is the recommended value by Gudmundsson[7] for multi-engine aircrafts. And for lateral static stability, StratoKiwi and StratoDodo were found to be slightly more stable compared to its competitor aircrafts.

6. Structure Analysis

After the final iterations of preliminary sizing was reached and agreed upon, design of StratoKiwi and StratoDodo was frozen and more detailed analysis was done to ensure its compliance to the regulation and the DRO. For this, analysis related to structural integrity and material selection was carried out. For each aircraft's structural component, load identification was done and the structural stress was estimated to determine the appropriate material for each component and ensure its structural integrity. In this chapter, this structural analysis will be described and its results will be outlined.

6.1. Approach to Material Selection

In the preliminary design phase, it is necessary to consider what material types the major components shall have in order to assess whether the desired functions and strengths can be achieved. However, the assignment of one specific material (e.g. 300M) for each component is intentionally avoided in order not to restrict the future options. A general material category is selected during the proposal development phase, with a list of common materials under this category as candidates, keeping in line with what is easily procurable on the market. The final material choice can be then fixed in the post-contractual detailed design phase based on supplier availability (provider of raw material & provider of certified treatment processes), forecasted cost, and updated functional need.

At locations where the material selection is based on the demand for structural strength, the approach is to first consider the application of aluminium – a material which is easy to produce, light, and inexpensive, however mechanically weaker than its other metallic counterparts. If the location demands a higher structural integrity than that aluminium can provide or has a higher operating temperature, heavier and more expensive metals such as steel and titanium shall be considered. Composite materials are at the first hand only considered if the loading scenarios are expected to be relatively homogeneous, if the parts are not large (less suppliers for manufacturing of large composite parts), or at the request of other departments. This had been the case for the fuselage, where it was requested by the weights department that the weight of the fuselage to be significantly reduced in order to achieve the target empty structure weight. For all load cases, a safety factor of 1.5 is applied.

In the following sections, the decision process toward the material selected for each component is explained in more detail. Figure 6-1 shows the summary of the material used for each aircraft component.

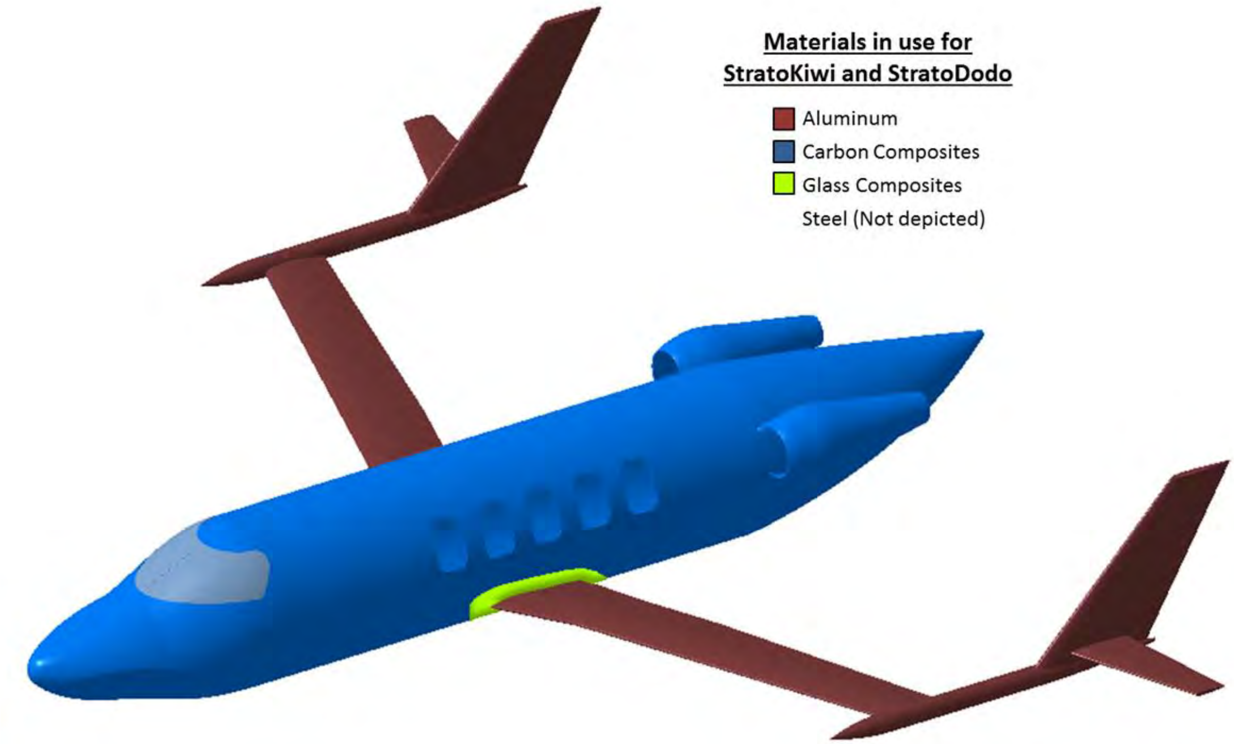


Figure 6-1: Material Group for each Aircraft Component

Modification of material is usually an extremely expensive process due to the re-certification process, possible redesign of adjacent parts, and potential retrofit actions. Therefore, it is important that a “good choice” of material is made early in the project, with consideration to other aspects of material selection aside from the mechanical properties. This means to aim for materials and treatment processes that are as easily procurable as possible over the 30 to 40 years expected project lifespan, and that it requires as little inspection and maintenance effort as possible for the operator (e.g. corrosion resistant materials and treatments, galvanic potential at interface of different components).

While assessing the availability of materials and parts for the long aircraft lifespan, it is also important to consider the environmental regulations which become stricter and stricter with time. Chemicals commonly applied in the aviation industry for corrosion resistance are slowly facing restrictions from the authorities due to their hazardous nature to the environment and/or to the health of human workers. It is thus possible that a material or coating chosen for the design might not be available on the market anymore before the end of project life, or that the operator would have limited supply of spare parts. An example for this is the planned prohibition of chromium plating from the European REACH regulation. Therefore, during the detail design phase, the development of regulations should also be considered for long-term material availability.

6.2. Wing Structure

6.2.1. Structural Layout

A multi-rib layout is chosen as the skeleton structure of the wings. The wing can be separated into multiple single-cell wingboxes via ribs as well as the forward and rear spar. Multiple stringers span across the upper and lower skins as additional support. On the inboard and middle wing segments, the wing ribs are parallel to flight path. On the outboard segment, the wing ribs are arranged perpendicular to the leading edge. This arrangement is decided to ensure that wing can be assembled together with or without the middle extension segment.

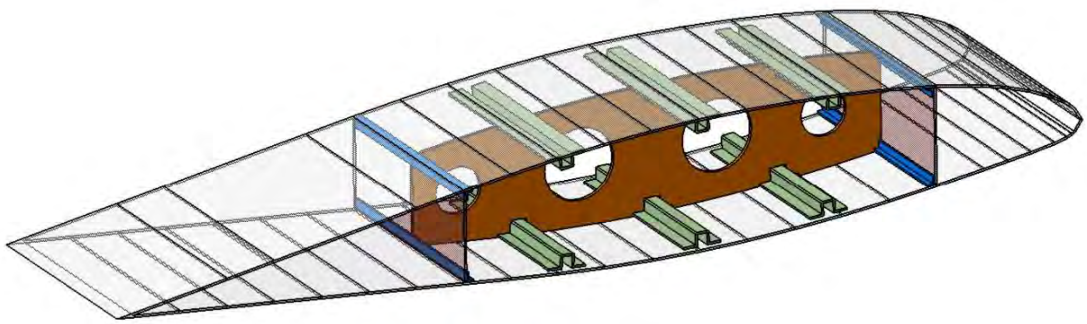


Figure 6-2: Multiple Wingbox Structure on Middle Wing Segment

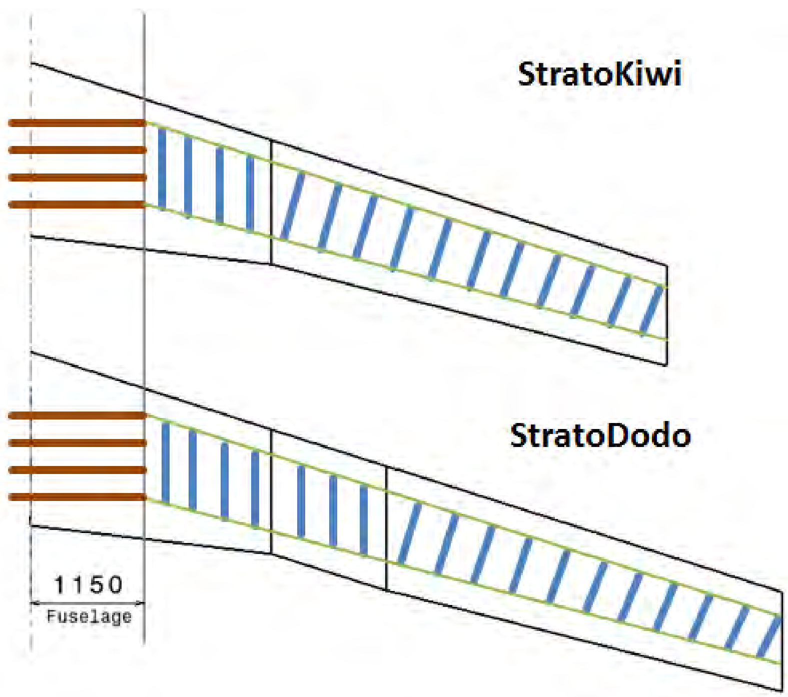


Figure 6-3: Layout of Ribs, Spars and Wingbox Structures

The forward spar and rear spar are located at 15% chord length and 65% chord length, respectively, of each airfoil section. This is due to the fact that fuel tanks usually span across the 15% to 65% chord. The ribs are 0.6m apart in average. With additional FEM analysis, it is possible to further optimize the location of these elements. Due to the OHVS configuration, the wing is expected to experience more torsional moment caused by the empennage at tip and must be strengthened accordingly to sustain these complex loads. Due to this high complication of multi-directional loads, metallic materials are preferred for the wing structure.

6.2.2. Wingbox Sizing

The wingbox was sized by first assessing the load distribution across the wing. Loads considered for this sizing are lift generated by the main wing, distributed weight of the wing structure, distributed fuel tank weight, lift generated by the empennage acting on the wing tip, and empennage weight of acting on the wing tip. These loads were multiplied by the maximum positive load factors in order to simulate the worst-case loading scenario. The resulting forces and bending moments are given in Figure 6-4 below.

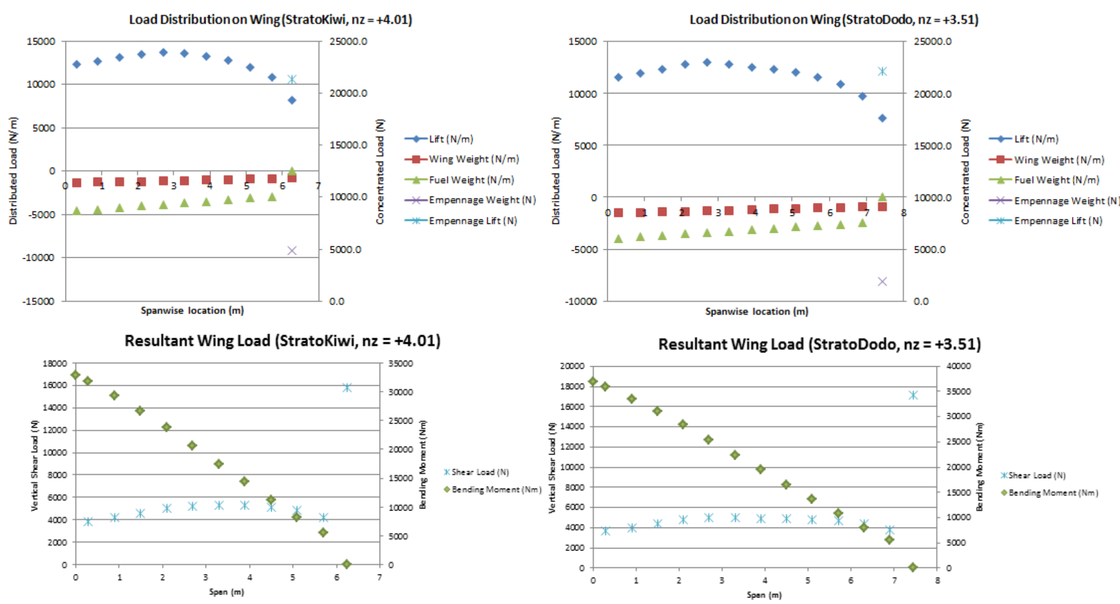


Figure 6-4: Load Distribution and Resultant Load on Wing Structure

A wingbox at 1.2m spanwise shall be sized, as this is the first wingbox beyond the radius of fuselage. Being the shared segment of both aircrafts, this location is sized according to the more severe loading case of the two. The resulting dimensions for spar caps, stringers, and skin are presented in Figure 6-5 below, and the materials selected are summarized in the following Table 6-1. As lower wing surfaces are cyclically loaded in tension and the upper surface in compression, the lower wing is very sensitive to crack propagation. Therefore, 2000 series aluminium (Al-Cu-Mn alloy) is chosen for the lower part of the wing, while the stronger 7000 series can be utilized for the other parts of the wing.

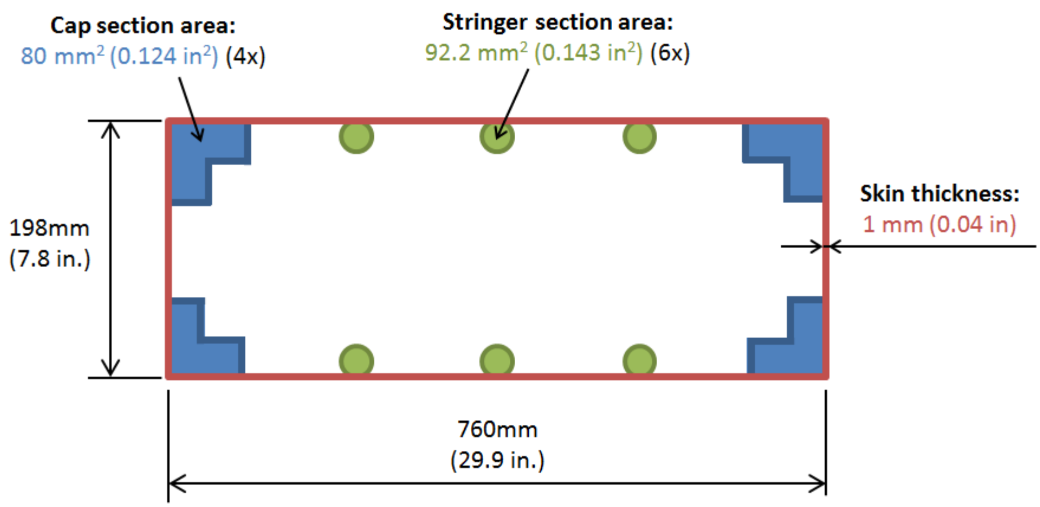


Figure 6-5: Wingbox Dimensions at Spanwise Location of 1.15 m

Table 6-1: Material Selection for Wingbox Structure

Item	Material Category	Material Candidates	Selection Criteria
Wingbox			
* Rib	Aluminium (7000 series)	AL 7085 AL 7075	Mechanical strength
* Spar	Aluminium (7000 series)	AL 7085 AL 7075	Mechanical strength
* Upper Stringer	Aluminium (7000 series)	AL 7055 AL 7075	Mechanical strength
* Lower Stringer	Aluminium (2000 series)	AL 2026 AL 2024	Resistance to crack propagation
* Upper skin	Aluminium (7000 series)	AL 7055 AL 7010	Mechanical strength
* Lower skin	Aluminium (2000 series)	AL 2026 AL 2024	Resistance to crack propagation

6.3. Fuselage Structure

6.3.1. Request on Material Type

The material selection for the fuselage is driven by the request for weight saving by the aircraft weights department. From the result of class II weight estimation, it was discovered that the aircraft would be overweight from the target structural weight from the initial sizing phase. Weight reduction possibilities were investigated, and the fuselage was identified as one of the larger components with great weight saving potential via the substitution of material type. By using composite material instead of the commonly-used aluminium to construct the fuselage, the overall aircraft could achieve a weight saving of 150kg and 250 kg, for StratoKiwi and StratoDodo respectively.

Therefore, it was decided that the fuselage would be constructed by composite materials, and the structures department shall size the fuselage according to the properties of common materials belongs to the composite material category.

6.3.2. Fuselage Sizing

Several critical scenarios are commonly considered to size a fuselage of a conventional aircraft layout, and the criticality of these scenarios is reviewed for the OHVS configuration in Table 6-2 below.

Table 6-2: Critical Load Scenarios for Fuselage Structure

No.	Critical Scenarios for Conventional A/C Configuration	Applicability of Scenario with OHVS Configuration
1	Critical loading of wing	Should be considered.
2	Critical loading of HTP and VTP	Direct empennage loading not on fuselage, therefore less bending moment on fuselage due to HTP and less torsion on aft fuselage due to VTP. However, HTP and VTP at wingtip cause torsion on the main wing which is transmitted to the fuselage should be considered.
3	Critical loading of engine mount (if mounted on fuselage)	Should be considered.
4	Critical loading of LG	Should be considered in landing scenarios; drag caused by extended LG should be considered for aircraft approach.
5	Critical loading of water loads	Not applied (Not common mission for business jets)
6	Critical loading of emergency landing	Should be considered.

For the scope of this preliminary sizing, the cross section of the fuselage at the location of aircraft center of gravity in cruise flight is observed. Loads considered includes lift force of a wing under maximum positive gust load factor, pitch-down moment caused by the high-mounted engine, torsion caused by banking maneuver with HTP, cabin pressurization. The worst-case scenario is assumed when all of the loads occur simultaneously. This is not a likely event, but it is applied as a penalty to compensate for the simplification of this analysis model and intended to cover also the dynamic loads. Precise loading scenarios as well as detailed FEM models must be used in the design phase to have a sharper picture of the actual loads acting on the fuselage.

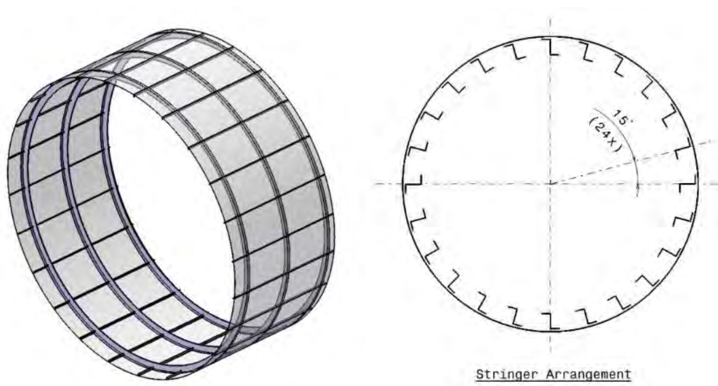


Figure 6-6: Fuselage Stringer Arrangement

24 Z-shaped stringers are installed around the fuselage circumference with 15° spacing between each. The fuselage segment is further divided into four smaller panels which allows for easier manufacturing processes. As suggested by XXX, the crown quadrant spans across a 90° - 99° arc on the top of fuselage, the two side quadrants cover each 113.5°, and the keel quadrant closes the bottom remaining section. The frames are placed 0.4 meter apart.

The final stringer dimension and skin thickness can be found in Figure 6-7 below. We can notice that the stringer cross section and skin thickness needed are significantly smaller than that from conventional aircrafts of similar magnitude. This is due to two reasons: (1) Empennage is not directly attached to the end tip of fuselage, and (2) HTP is generating upward lift instead of downward lift. Therefore, the bending and torsional moments acting on the overall fuselage frame are much smaller, resulting in a fuselage which can be lighter than the statistical average. The wingbox segment would have to be additionally reinforced due to the greater torsional loads coming from the empennage at wing tip.

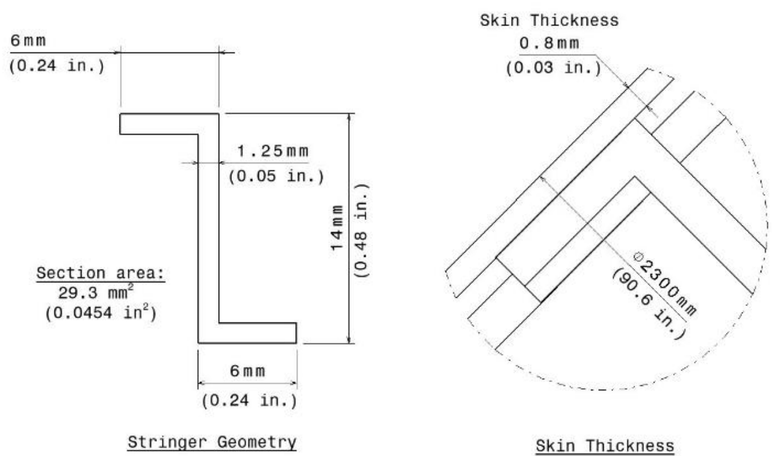


Figure 6-7: Dimensions of Fuselage Stringer and Skin

6.3.3. Corrosion Resistance at Wing Junction

One of the significant issues of using both composite and aluminium materials on an aircraft is corrosion. As the wings of StratoKiwi and StratoDodo are expected to be constructed in aluminium and the fuselage with carbon composites, the junction is prone to severe corrosion due to the difference in galvanic potential of these two materials. A solution to prevent this is to insulate the galvanic potentials via fiberglass composite or titanium, as can be seen on Figure 6-1. The fiberglass composite is selected as the main material for the wingbox junction due to its lower weight. Titanium can also be considered for some components of the wingbox if additional strength is needed. Table 6-3 summarizes the material selection of fuselage components with all the above-mentioned considerations.

Table 6-3: Material Selection for Fuselage Structure

Item	Material Category	Material Candidates	Selection Criteria
Fuslage			
* Stringer	Composite (Carbon)	Carbon AS4-Epoxy (e.g. AS4/3501-6, ...)	Weight saving benefits
* Frame	Composite (Carbon)	Carbon AS4-Epoxy (e.g. AS4/3501-6, ...)	Weight saving benefits
* Skin	Composite (Carbon)	Carbon AS4-Epoxy (e.g. AS4/938, AS4/8552, ...)	Weight saving benefits
* Wingbox Junction	Composite (Glass)	S-901 Glass Epoxy E-Glass Epoxy	Isolation of galvanic potential, weight saving benefits
	Titanium	Ti 6Al 4V	Isolation of galvanic potential, mechanical strength

6.4. OHVS Structure

6.4.1. Structural Layout

An important analysis to reassure the feasibility of the OHVS configuration is the structural analysis of the OHVS junction connecting the main wing to the empennage. As mentioned in the previous chapters, the distance between the wing's 25% tip chord and HTP's 25% root chord must be 2 to 5 times the wing tip chord length. This would lead to a long boom length and thus a long bending moment arm as well as larger component weight. Also, due to the small thickness ratio of the wing, structural reinforcements allowable at the junction as well as the boom size are limited. This analysis aims to determine approximate dimensions of the structure, identify materials which can meet both the strength and weight requirements, and thus confirm the feasibility of the OHVS junction.

The shape of this boom is first approximated by a hollow cylinder shaft. The hollow center is intended to allow passage for the hydraulic lines. As the wingtip has a thickness of 8cm, the hollow shaft is expected to have an outer diameter of a similar magnitude.

6.4.2. OHVS Boom Sizing

The boom is assumed to be a beam fixed at the main wing leading edge tip. This boom will be loaded by the lift generated by HTP, the weight of HTP, the aerodynamic force generated by VTP, the distributed weight of the OHVS boom itself, and the distributed weight of the VTP. The first three loads will cause torsional loading on the OHVS boom, while the remaining loads would create a bending moment. The distribution of these loads can be seen on Figure 6-8.

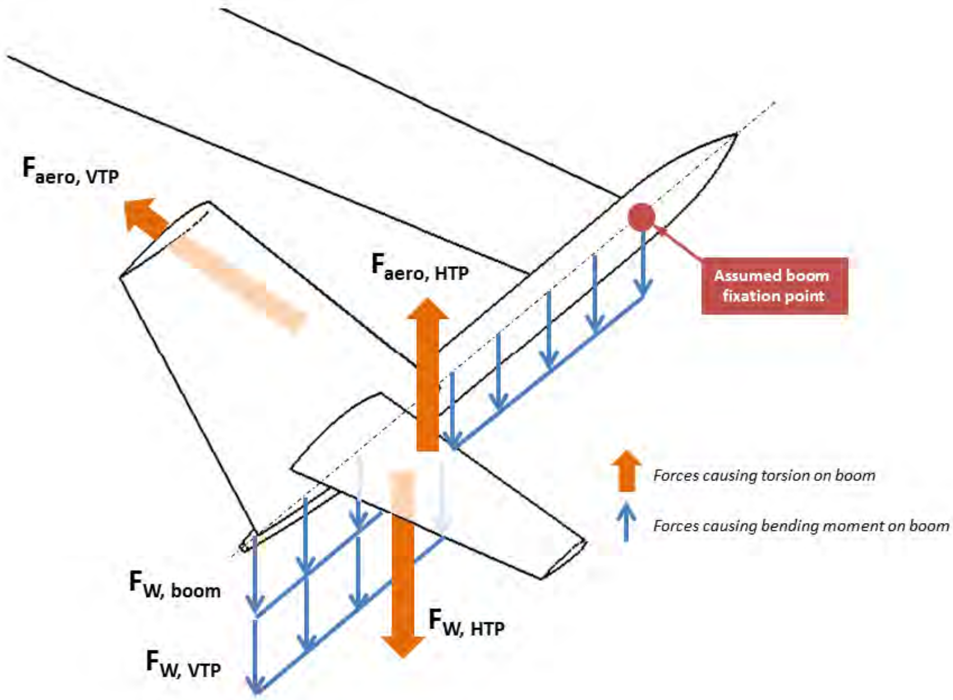


Figure 6-8: Loads acting on OHVS Boom

Three loading scenarios were considered which are suspected to cause most severe loading on the empennage, and thus on the OHVS boom:

- **Scenario 1:** One engine failure at sea level
- **Scenario 2:** Maximum sidewind at sea level
- **Scenario 3:** Maximum positive load factor during cruise

By comparing the resultant tensile and shear loads on the OHVS boom, it was observed that scenario 3 causes the most severe loading. For StratoDodo, the maximum shear stress is the limiting factor, while for StratoKiwi, it is the maximum tensile stress caused by the higher positive load factor. The sizing is thus continued by analyzing whether it is possible for a shared joint structure to sustain the scenario 3 loading with the mechanical properties of common aerospace-grade aluminium. After several iterations, an optimum cross section of the OHVS beam is found to be of 7cm inner diameter and 10cm outer diameter, if the application of 7075-T6 aluminium is considered. This would also lead to an estimated mass of 53.2 kg for each OHVS boom, which is even lighter than the 85 kg estimated in the class II weight estimation.

A more detailed FEM and CFD analysis, as well as the consideration of more complex maneuvering loads, would be needed on this junction in order to be able to fully size this OHVS boom junction. However, this brief analysis is a first confirmation on the feasibility of using aluminium for the construction of the OHVS boom, and that the target boom weight can be achieved.

Table 6-4: Maximum Stress in OHVS due to Loading Scenario 3

	F_{TY}	F_{SU}
	[MPa]	[MPa]
Alu 7075-T6 (sheet) - extrusions	496	290

	Max. bending stress	Max. shear stress
	[MPa]	[MPa]
Kiwi	197	200.609
Dodo	172.5	205.903

Table 6-5: Material Selection for Empennage Structure

Item	Material Category	Material Candidates	Selection Criteria
Empennage			
* OHVS Boom	Aluminium (7000 series)	AL 7075 AL 7085	Mechanical strength, weight saving benefits
* VTP	Aluminium (7000 series)	AL 7075 AL 7085	Mechanical strength, weight saving benefits
* HTP	Aluminium (7000 series)	AL 7075 AL 7085	Mechanical strength, weight saving benefits

6.5. Landing Gear Structure

6.5.1. Landing Gear Layout

In order to maximize shared weight in the family concept, the same landing gear system with retractable, oleo-pneumatic struts is utilized on both StratoKiwi and StratoDodo. Retractable landing gears are selected as the aircraft would be cruising at around a high airspeed of Mach 0.85, and fixed landing gears are not suitable for this scenario. Due to static stability requirements, the NLG is located near the tip of the aircraft and the MLG is located on the fuselage. Having no storage capacity in case of a forward retraction, the NLG is decided to have a rearward retraction mechanism. The MLG on the fuselage shall have an inward retraction mechanism as shown in Figure 6-9.

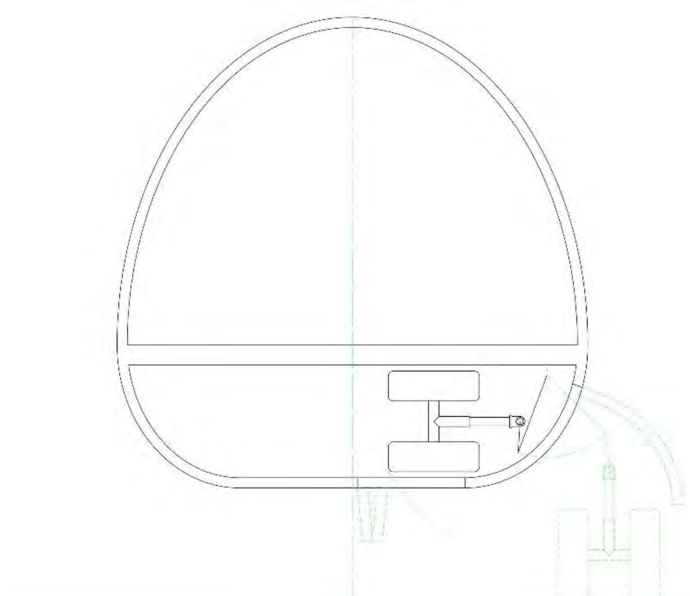


Figure 6-9: Landing Gear Retraction Mechanism

An oil-pneumatic shock absorber filled with nitrogen and common aviation standard MIL-PRF-5606 oil is designed for StratoKiwi and StratoDodo. A one-chamber shock absorber is prone to cause oil foaming oil at the time of shock, therefore degrading its efficiency. Due to this reason, the shock absorbers contain separate nitrogen and oil chambers. A metering pin with increasing pin diameter inside the strut controls the amount of fluid flowing through an orifice, and in this way damp the landing impact on the aircraft.

Both the MLG and NLG have the height of 1.1m under static load, required by the stability and clearance analysis mentioned in section 4.7. The effective shock absorber length required is 28.3 cm, with a travel of 9.43 cm in a MLW two-point landing scenario. The maximum braking energy allowable is designed to be 5 MJ per MLG. In the case of hydraulic failure, the electro/mechanical backup system would ensure the extension of the landing gear, while downlock springs on the side braces secure the down and locked position mechanically. Torque links are positioned behind the shock absorbers in order to minimize the risks associated with bird strikes.

6.5.2. Tire Sizing

The tire sizing is based on static and dynamic loads to be sustained by each tire, obtained during the class I sizing. An additional growth factor of 25% is added to the actual loads in order to allow margin for future aircraft family expansion. A common minimum rated speed of 180 MPH is also taken into account in the selection.

While considering whether to utilize one tire or two tires per main landing gear strut of StratoKiwi and StratoDodo, the following drawbacks for the one-tire option are identified:

- Load to be sustained would require the selection of a significantly oversized tire due to the lack of intermediate options from the tire manufacturer catalogue.

  → LG is oversized for StratoDodo, significantly oversized for StratoKiwi.

  → Additional weight of 110 kg per aircraft, compared to the option with two tires per strut.

- With one of the aircrafts entering into service within 3 years and also in consideration of cost, it is not advantageous for the program to request the development of a customized part.

- The two-tire option can be conducted with a simpler bell crank system with one rotation axis. However, to accommodate the large tire in the fuselage section in retracted status, a more complex retraction system concerning multi-axis rotations would be necessary.

  → Higher development and acquisition cost for complex retraction systems

  → Higher system weight

  → Higher failure rates and jamming in in-service phase

Therefore, the two-tire option is selected for the MLG of the program, using four 17.5" x 5.75" main tires per A/C. For the NLG, one single 15"x 6" tire is sufficient to sustain the target sizing loads.

Table 6-6: Tire Candidate for MLG and NLG

1. MLG Tire Candidates

|| Option 1 || 2 tires per strut Max. static tire load: **4376** lbs	Size	Ply Rating	Rated Speed	Rated Load	Mx. Braking Load	Weight (Estimated)	Price (Estimated)
	-	-	[MPH]	[lbf]	[lbf]	[lbf]	-
MLG Selected -->	17.5x5.75-8	12	210	5000	7500	14.8	544 USD
	19.5x6.75-8	10	190	4270	6400	13.24	339 USD
	19.5x6.75-8	10	225	4270	6400	17.85	633 USD

|| Option 2 || 1 tire per strut Max. static tire load: **8752** lbs	Size	Ply Rating	Rated Speed	Rated Load	Mx. Braking Load	Weight (Estimated)	Price (Estimated)
	-	-	[MPH]	[lbf]	[lbf]	[lbf]	-
	H22x8.25-10	14	190	8300	12500	31.73	880 USD
	24x7.25-12	12	190	8150	12200	28.45	760 USD
	B24x9.5-10.5	18	210	12200	18300	42.11	1732 USD

2. NLG Tire Candidates

Max. static tire load: **3410** lbs Max. dynamic tire load: **5115** lbs	Size	Ply Rating	Rated Speed	Rated Load	Mx. Braking Load	Weight (Estimated)	Price (Estimated)
	-	-	[MPH]	[lbf]	[lbf]	[lbf]	-
	14.5x5.5-6	14	210	2800	4200	13.15	895 USD
	15x6.0-6	10	160	3200	4800	10.28	359 USD
	15x6.0-6	10	160	3200	4640	11	380 USD
NLG Selected -->	15x6.0-6	10	210	3410	5115	12.31	418 USD

6.5.3. Material Selection & Corrosion Resistance

Ensuring the corrosion resistance of landing gear structure as well as resistance to stone- and birdstrikes are crucial in reducing maintenance cost and ensuring aircraft availability. Corrosion resistance is especially crucial for frequent operations or long-time parking in airfields near sea, where the salt in air drastically accelerate the pace of corrosion. Thus, the following practices are applied on the detail design of landing gear components:

- Application of primer coating on steel parts which are not rustproof.
- Anodizing aluminium parts to create a protective layer, and application of alodine. Application of HVOF (High Velocity Oxygen Fuel Coatings) can also be considered in compliance to the European REACH regulation on the gradual prohibition of chromates.
- Insulation of metallic parts with big difference in galvanic potential via other materials or insulation coatings
- Allowing additional margin of material thickness during design in order to allow local repairs with minimize prohibition on aircraft operability.

Table 6-7: Material Selection for Landing Gear

Item	Material Category	Material Candidates	Selection Criteria
Landing Gears			
* Main fitting	Steel	SAE 4130 SAE 4340 300M	Mechanical strength
* Side brace / drag br	Aluminium	AL 7075 AL 7085	Weight saving benefits
* Pintle Pin	Steel	Same as for main fitting	Mechanical strength
* Sliding Tube	Steel	Same as for main fitting	Mechanical strength
* Torque Link	Aluminium	AL 7075 AL 7085	Weight saving benefits
* Wheel rims	Steel	Same as for main fitting	Mechanical strength
* Brakes	Carbon	-	Low thermal expansion, high heat sink capacity and heat conductivity per specific weight
* Bearings	Bronze	C93800 C93600 C93200	High Strength and abrasion resistance
* Retraction Actuator / Downlock Actuator			
** Piston	Steel	Same as for main fitting	Mechanical strength
** Rod	Steel	Same as for main fitting	Mechanical strength

7. System Design Choices

7.1. ATA 21 – Air Conditioning System

The aircrafts will have an air conditioning system that supplies airflow to the cockpit and passenger cabin for ventilation and pressurization. It also controls the temperature and humidity of the air. This system includes distribution, pressurization control, cooling, and temperature control. All the control is to be managed from the cockpit. Hot pressurized air is taken from the engines and/or APU and a portion of it is send to the PACK 1 and/or PACK 2 to cool to the cold air mixer unit. The other portion of hot air is send to the hot air manifold to increase the final temperature on the 3 aircraft zones as shown in Figure 7-1.

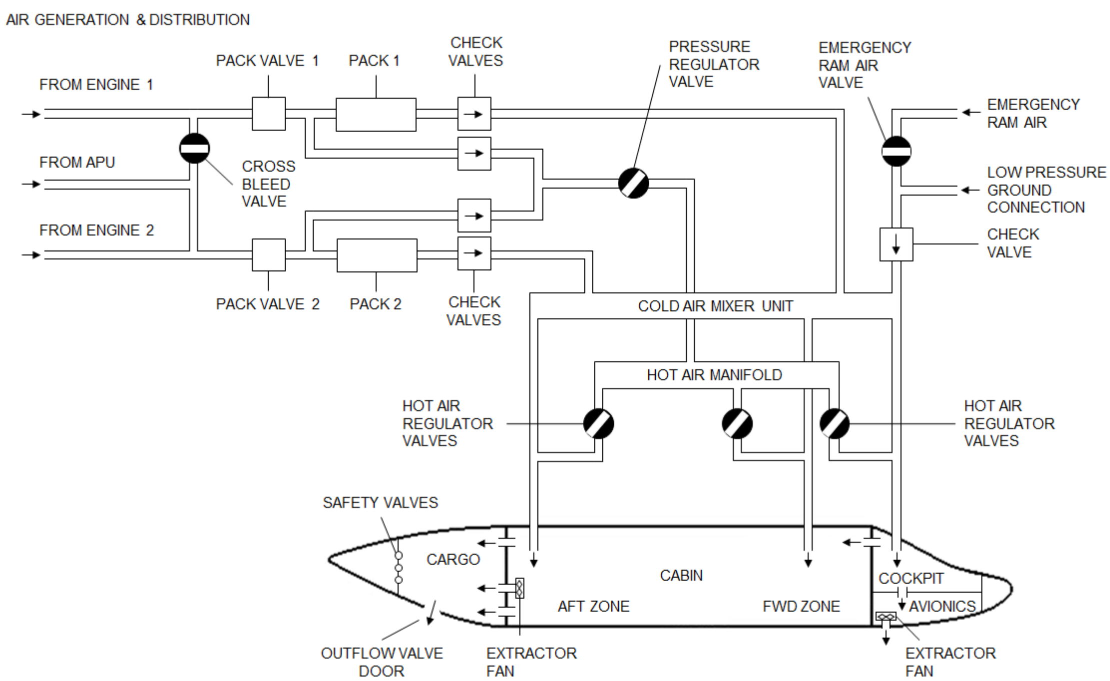


Figure 7-1: Schematics of Air Conditioning System for StratoKiwi and StratoDodo

7.2. ATA 24 – Electrical Power System

The electrical power system generates and supplies AC (Alternating Current) and DC (Direct Current) power to the airplane. This system also supplies automatic and manual controls for the flight crew. For StratoKiwi and StratoDodo, each will have one electrical generator on each engine accessories gearbox, and one APU generator on the Auxiliary Power Unit (APU). These generators provide 115VAC, 400Hz to the aircraft electrical network. On ground, the aircraft network can be powered by the APU Generator or an external power source that provides 115VAC and 400Hz as well. On emergency conditions, an Emergency Generator connected to the Ram Air Turbine (RAT) powers the aircraft electrical network with 115VAC, 400Hz. These sources will supply the aircraft electrical network AC/DC thru the transformer rectifier units.

The aircrafts will have two main batteries that work at 28VDC used to start the APU. In case of an emergency, the batteries will supply the aircraft electrical network thru the Static Inverter. This system also has circuit breakers and relays to avoid any overcharge on the electrical network.

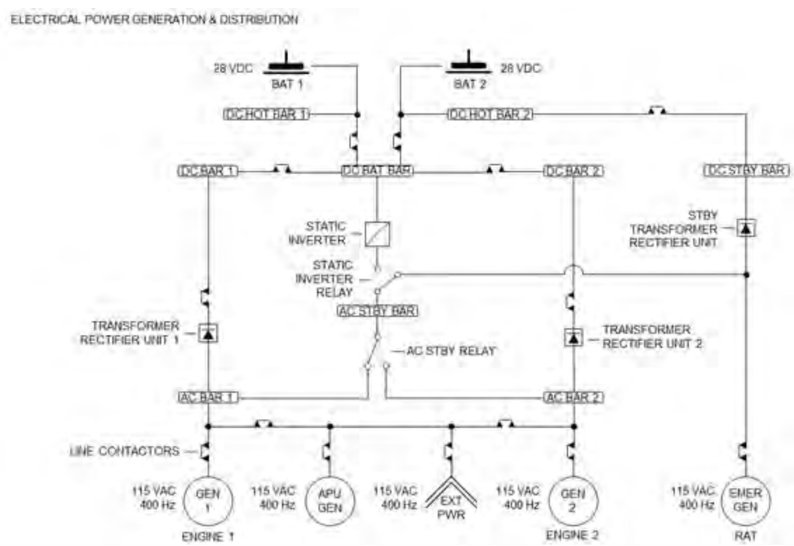


Figure 7-2: Schematics of Electrical Power System for StratoKiwi and StratoDodo

7.3. ATA 27 – Flight Controls System

The aircraft primary flight controls, elevon and rudders are mechanically operated by conventional mechanical means, such as control cables, bell cranks and push-pull rods. Electrical trim systems are installed for trimming in yaw, roll and pitch axes. Pitch trim is accomplished by moving the horizontal stabilizer. The pitch trim has a backup system, which also operates electrically. The trailing edge flaps are electrically operated.

7.4. ATA 28 – Fuel System

The fuel system contains and supplies fuel to the engines and the APU. This system is powered by AC and DC power bar. The system is controlled and monitored, and all the indications (Fuel quantity, Fuel Pump status, Fuel Valves position, etc.) are showed to the flight crew on the Systems Monitoring Display. The fuel system also provides sufficient redundancy to ensure that the possibility of a fuel system failure resulting in a catastrophic event is reduced to an extremely remote probability.

The fuel is stored in integral wing tanks, forward central tank, aft central tank and wingbox tanks, and it is distributed thru fuel transfer valves and fuel pumps. In normal operation, each wing tank supplies fuel to one engine only. The fuel pumps at central tanks are submerged, ensuring a constant fuel flow to the engines. A vent system is designed to ensure that the differential pressure between the tank and ambient air remains within structural limits and to prevent fuel spillage during flight manoeuvers.

The aircraft can be pressure refueled or defueled at the right wing with the single-point refueling adapter and the refuel/defuel control panel. Pressure refuel and defuel operations can be accomplished with aircraft battery power.

7.5. ATA 29 – Hydraulic Power

The aircrafts are provided with a hydraulic power system designed to supply power sufficient (up to 3000 psi) to meet the performance and redundancy requirements of safe flight. This system is used to operate the following aircraft systems and components that require high power and accurate control of primary flight controls, landing gear, nose wheel steering, main landing gear brakes, and thrust reversers. The aircraft hydraulic power is supplied by three independent hydraulic systems. Systems No. 1 and No. 2 use an Engine Driven Pump as a primary source of hydraulic power and an electric pump as a standby source. System No. 3 has one electric pump for regular use and a second electric pump available for high flow requirements. A Power Transfer Unit is installed to allow to transfer power between systems No. 1 and No. 2 in the event of a EDP failure (both directions). The fluid temperature, pressure, quantity and hydraulics pump condition is available for the flight crew on the Systems Monitoring Display.

7.6. ATA – 32 Landing Gear

The landing gear is retractable tricycle type. The nose landing gear is single wheeled, while the main landing gear is double wheeled. The aircraft may be operated on paved runways only. The landing gear is operated by a hydraulic system, which also keeps the main landing gear locked in the up position. The main landing gear is kept locked in the up position by mechanical locks. The nose landing gear incorporates a mechanical steering system, which performs the airplane directional control on the ground from the cockpit.

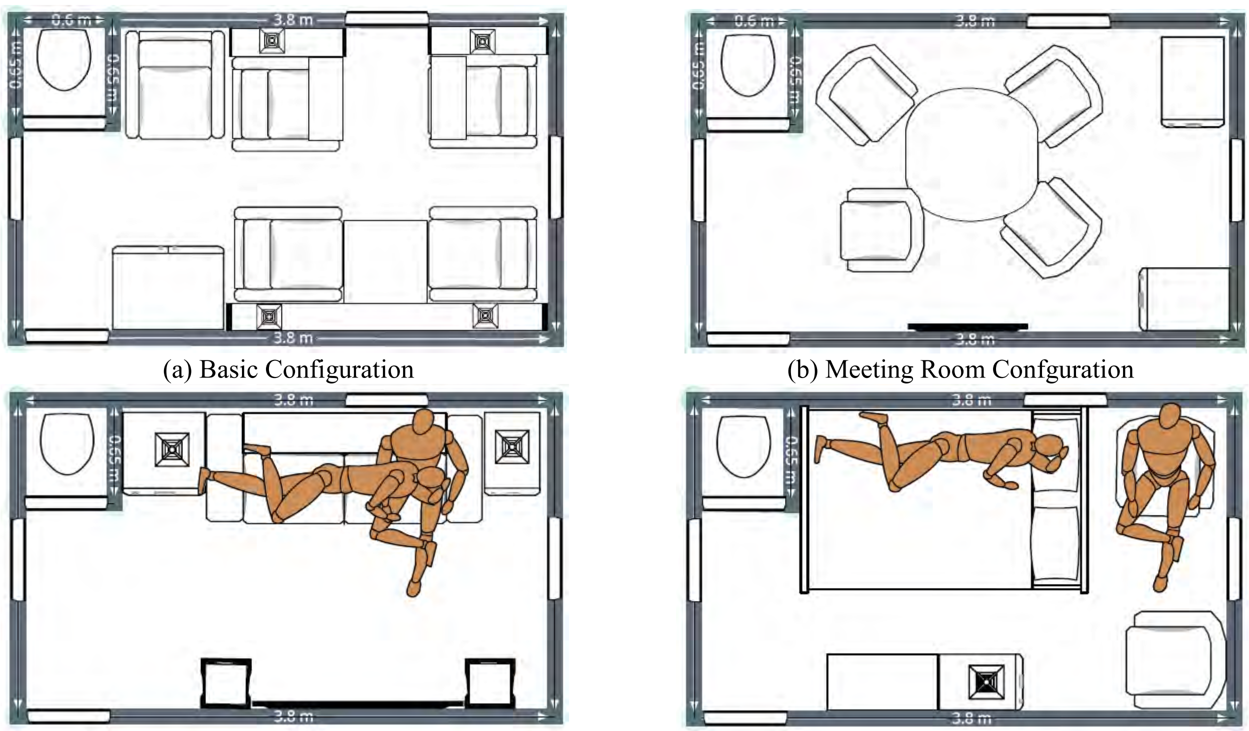
The landing gear and brake system parameters and indications are displayed on the Systems Monitoring Display. The air/ground positioning system is composed by one weight-on-wheel (WOW) proximity switch installed on each main landing gear strut. These proximity switches, actuated by the airplane weight provide information to the other airplane systems whether the airplane is on ground or in flight. The main brake consists of a brake-by-wire system controlled by either the Pilot or Co-pilot via the rudder pedals. When the hydraulic system fails, the Emergency/Parking brake is available.

8. Interior Design

8.1. Cabin Configurations

For a business jet, cabin interior plays an important role in attracting buyer. In contrast with the conventional commercial aircraft, business jet cabin is often highly customizable to need a specific need and demand of the buyer. Thus, it is beneficial to offer several cabin configurations to attract more buyer, be it for private or enterprise. With this in mind, four cabin configurations are proposed for each aircraft. These configurations are basic, meeting room, living room, and bedroom configuration. These four cabin configurations were designed to share the same base design that includes one lavatory, one main door, one door to cargo compartment, and one emergency door that is placed above the wing for compliance with FAR 23. And FAR 25. The schematics of these four cabin configurations are presented in the following Figure 8-1 and Figure 8-2 while its design considerations are described below.

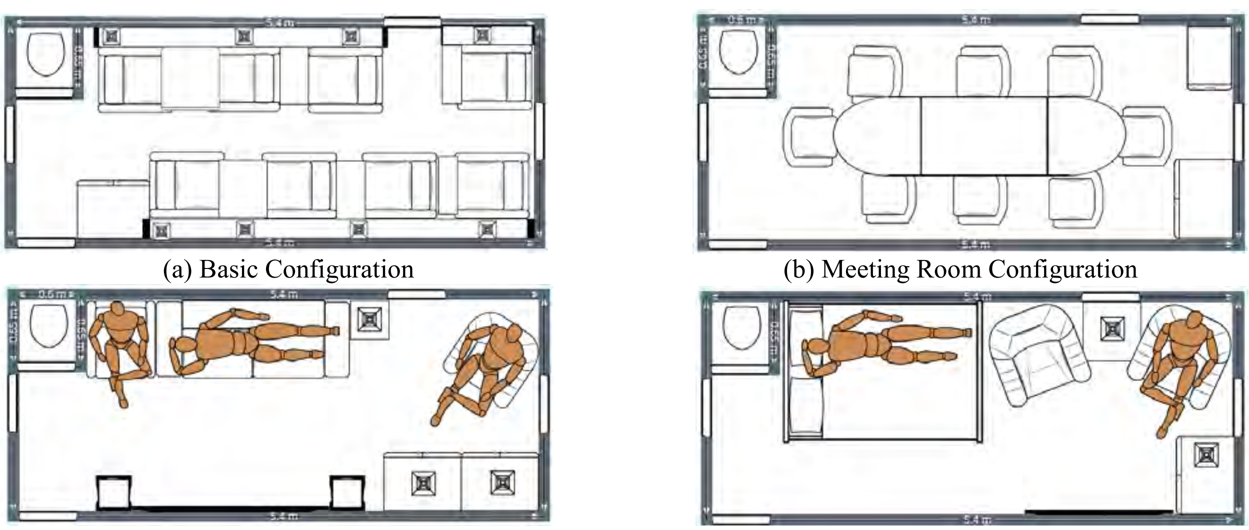
- Basic configuration was designed to fit the maximum passenger in the cabin and this is the cabin configuration that was design to comply with the maximum passenger requirement stated by the DRO.
- Meeting room cabin configuration was designed for a group of company executive team with busy schedule. This cabin configuration is aimed to allow the passenger to remain productive during the flight by conducting some meeting or work inside the cabin. The chairs in the meeting room are designed to be able to rotate in order to face and fix in the direction of the nose and during take-off and landing while during other flight phases, it can be turned toface the meeting table.
- The living room cabin configuration was designed for passengers to enjoy their leisure time during the flight. The living room configuration will be a two-seated cabin for StratoKiwi and a four-seated cabin for StratoDodo. The sofa is designed to have seat belts and is capable of meeting 16g dynamic impact for safety issue. The armchair in StratoDodo is also designed to be able to rotate and rotate in order to face and fix in the direction of the nose.
- The bedroom cabin configuration was designed for passengers to be able to have a decent rest on the aircraft during the flight. It is designed to be only two-seated for both StratoKiwi and StratoDodo. In this cabin configuration, passengers will need to sit on the chair during take-off and landing.



(a) Basic Configuration (b) Meeting Room Confguration

(c) Living Room Configuration (d) Bedroom Configuration

Figure 8-1: Proposed Cabin Configuration for StratoKiwi



(a) Basic Configuration (b) Meeting Room Configuration

(c) Living Room Configuration (d) Bedroom Configuration

Figure 8-2: Proposed Cabin Configurations for StratoDodo

8.2. Cockpit Design

As for the cockpit design of StratoKiwi and StratoDodo, “No lights, no sounds” cockpit type will be used to accommodates two pilots with comfort during all flight phases, with minimum workload and maximum safety. The cockpit is separated from the passenger cabin by a partition with a lockable door. When a light or a sound is triggered on the cockpit, it is related to an abnormal condition and it will be followed by the related crew correction actions.

The design schematics of the cockpit is shown by Figure 8-3.

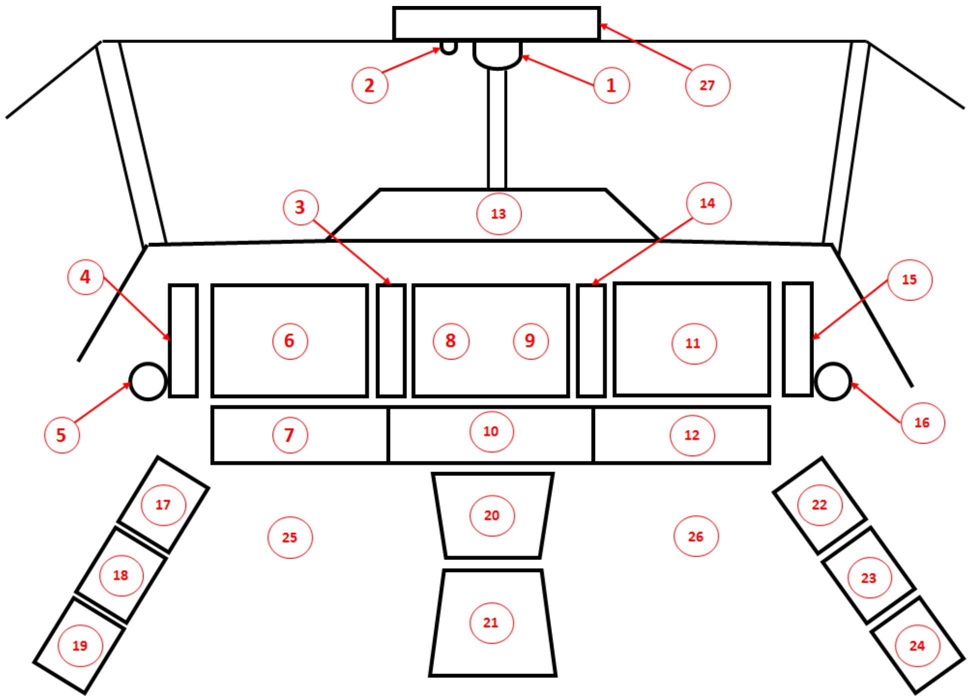


Figure 8-3: Cockpit Schematics for StratoKiwi and StratoDodo

Table 8-1: Part Number Description for Cockpit Schematics

1. Stand-by Compass
2. Cockpit Microphone
3. Captain Navigation & Systems Monitoring Control Panel
4. Captain Primary Display Control Panel & Alarms (Master Warning, Caution Warning, EGPWS Warning)
5. Left Hand Speaker
6. Captain Primary Display (Altitude, Speed, Vertical Speed, Heading, Sideslip, Attitude, DME, ILS, AP, FMS, etc.)
7. Captain Communication Control Panel
8. Navigation Display
9. Systems Monitoring Display
10. Systems Control Panel (APU, Landing Gear Lever, Fuel Pumps, Hydraulic Pumps, Pressurization and Air Conditioning System)
11. First Officer Primary Display (Altitude, Speed, Vertical Speed, Heading, Sideslip, Attitude, DME, ILS, AP, FMS, etc.)
12. First Officer Communication Control Panel
13. Flight Control Panel (Flight Management System, Auto Pilot System) and Stand-by Instruments
14. First Officer Navigation & Systems Monitoring Control Panel
15. First Officer Primary Display Control Panel & Alarms (Master Warning, Caution Warning, EGPWS Warning)
16. Right Hand Speaker
17. Captain Multipurpose Control and Display Unit
18. Left Hand Aircraft Steering
19. Captain Oxygen Mask
20. Fire Extinguishing System (Engines, Cargo and APU), Anti-Ice System
21. Engine Control Panel (Engine Master Switch, Engine Control Lever), Flaps Lever, Parking Break Switch, Passenger Address Microphone, Emergency Landing Gear Lever
22. First Officer Multipurpose Control and Display Unit
23. Right Hand Aircraft Steering
24. First Officer Oxygen Mask
25. Captain Yoke Control and Breaking and Rudder Panels
26. First Officer Yoke Control and Breaking and Rudder Panels
27. Lights Control Panel, Electrical Systems Control Panel, Recording Systems Control Panel

9. Cost Analysis

In accordance with Bombardier Business Aircraft Market Forecast 2016-2025, the Business market will required 13,000 aircraft. Larger aircraft will dominate the market, but the new business jet deliveries for North America, Europe and China, are presented as a great opportunity to sell new business jet family. Besides, according to Bombardier, the new aircraft deliveries have stabilized since 2014. This means an excellent opportunity for a new business jet family, such as Strato Family to enter the business jet market. Based on this market forecast, it was also agreed to try to reach 3.14% of business jet market, 1.57% for each model and try to sell 130 airplanes of each model.

With this market reach target in mind, the life cycle cost was estimated based on Roskam [20] and details of the each cost are listed in the table below.

Table 9-1: Estimation of Non-Recurring Cost (Research, Development, Test and Evaluation (RDTE))

		StratoKiwi	StratoDodo
Airframe Engineering and Design Cost	[USD]	331,699	398,335
Development Support and Testing Cost		3,716,334	4,360,355
Flight Test Airplanes Cost		77,160,060	88,503,227
Flight Test Operations Cost		240,276	297,122
Test and Simulation Facilities Cost		3,742,362	12,474,539
RDTE Profit Cost		3,742,362	12,474,539
Cost to finance the RDTE phases		1,871,181	6,237,269
Research, Development, Test and Evaluation		37,423,616	124,745,385

Table 9-2: Estioamtion of Fly-Away Cost (Manufacturing and Acquisition)

		Kiwi	Dodo
Airframe Engineering and Design Cost	[USD]	3,585,578	4,129,306
Airplane Production Cost		488,993,971	553,300,197
Production Flight Test Operations Cost		2,685,246	2,685,246
Cost of financing the manufacturing program		26,066,568	29,479,724
Manufacturing and Acquisition Cost		521,331,362	589,594,473
Manufacture Profit Cost		52,133,136	58,959,447
Total Acquisition Cost		573,464,498	648,553,921

Table 9-3: Estimation of Operating Cost

		Kiwi	Dodo
Program Operating Cost	[USD]	4,858,387,811	5,694,025,580

Table 9-4: Estimation of Life-Cycle Cost

		Kiwi	Dodo
Life Cycle Cost	[USD]	5,469,275,925	6,467,324,886

Table 9-5: Estimation of Direct Operation Cost

Direct		Kiwi	Dodo
Flying	[USD/nm]	0.78	0.94
Maintenance		0.67	0.73
Depreciation		0.45	0.55
Landing fees, navigation fees and registry taxes		0.23	0.28
financing		0.16	0.19
Direct Operating Cost		2.29	2.68
Indirect Operating Cost		0.57	0.67

10. Conclusion

From the RFP proposed by AIAA, DRO was formulated and then two-member family business jet aircrafts, StratoKiwi and StratoDodo were designed. After numerous design iterations, the design of both aircrafts were frozen and detailed performance, structure, and cost analysis were done. From these analysis, the aircrafts' compliance were successfully proven. For convenience, compliance with each item on DRO and their corresponding discussion section is outlined in the following Table 10-1

Table 10-1: DRO Compliance Matrix for StratoKiwi and StratoDodo

	DRO		Proposed Design		Related Section
	6-seater	8-seater	StratoKiwi	StratoDodo	
Certification	FAR 23	FAR 25	FAR 23	FAR 25	
Expected Entry into Service (EIS)	2020	2022	2020	2022	
Number of Crew	1 or 2	2	1 or 2	2	8.2
Number of Passenger	up to 6	up to 8	6	8	4.5 and 8.1
Baggage Capacity	227 kg (500 lbs)	454 kg (1000 lbs)	227 kg (500 lbs)	454 kg (1000 lbs)	4.3 and 4.5
Take-Off Balance Field Length at MTOW with Dry Pavement at Sea Level ISA conditions	1219 m (4000 ft)		648 m (2126 ft)	900 m (2953 ft)	5.5.1
Maximum Landing Field Length at MLW	1097 m (3600 ft)		561 m (1840 ft)	610 m (2001 ft)	5.5.2
Rate of Climb in Clean Configuration with Maximum Take-Off Power at Sea Level ISA Condition	1067 m/min (3500 ft/min)		1775 m/min (5823 ft/min)	1344 m/min (4409 ft/min)	5.3
Rate of Climb in Clean Configuration at Cruise Ceiling (13716 m / 45000 ft)	91.4 m/min (300 ft/min)		565 m/min (1853 ft/min)	281 m/min (921 ft/min)	5.3
Rate of Climb in Clean Configuration at Service Ceiling (14326 m / 47000 ft)	30.4 m/min (100 ft/min)		455 m/min (1492 ft/min)	195 m/min (639 ft/min)	5.3
High Speed Cruise Speed and Altitude	Mach 0.85 at 10670 m (Mach 0.85 at 35000 ft)		Mach 0.89 at 10670 m (35000 ft)	Mach 0.89 at 10670 m (35000 ft)	5.3
Optimum (Long-Range) Cruise Speed and Altitude	Mach 0.80 at 13720 m (Mach 0.80 at 45000 ft)		Mach 0.80 at 13720 m (45000 ft)	Mach 0.80 at 13720 m (45000 ft)	2.1 and 5.4.1
Maximum Cruise Range	4630 km (2500 nmi) (with 2 passengers)	4630 km (2500 nmi) (with 4 passengers)	4703 km (2539 nmi)	4701 km (2538 nmi)	5.4.2
Service Ceiling	15545 m (47000 ft)		17200 m (56430 ft)	15420 m (50500)	5.3
MTOW	less than 5670 kg (12500 lbs)	close to 5670 kg (12500 lbs)	5300 kg	6550 kg	3.2
Empty Weight	-	120% of Kiwi's	2857 kg	3431 kg	3.2 and 4.5
Shared Structural and SystemWeight	70% Weight		91%	82%	4.1.3 and 4.5

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End of Report