Infinity

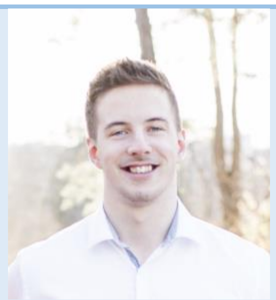
Aircraft Design - A380 Replacement

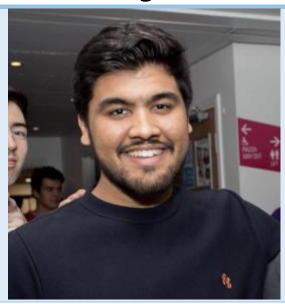
James Oliver Howe, Max Isaac Sandford, Simran Singh Panesar & George Stephen Smith

Aircraft Design – A380 Replacement

Group Members

James Howe ***Max Sandford*** ***Simran Singh Panesar*** ***George Smith***






Introduction

The A380 was an extremely ambitious aircraft with the intention to satisfy the growing demands of the air travel industry. With its vast seating capacity, long range and radical design, it was prepared to take the industry by storm. However, the test of time has shown that the industry is not ready for an aircraft of this scale. The primary issue for airlines is the difficulty in filling seats ensuring a cost-effective flight. Consequently, Airbus has seen a drop-in interest with airlines opting for smaller more efficient aircraft such as the 777-300ER, 787 and A350. As a result, a demand for a new more competitive high capacity aircraft has arisen.

Design Strategy

When designing a new aircraft, it is important to consider new technologies and configurations such that it will be competitive when released into market. Infinity employs this philosophy combined with proven configurations to produce a unique replacement for the A380. Infinity will feature conventional lightweight materials and composite structures to keep the gross mass of the aircraft down. It will also feature a conventional wing and tail plane configuration as these both provide sufficient aerodynamic properties to fly this aircraft. Looking forward, Infinity endeavours to use the newest turbofan technology to improve upon thrust and fuel efficiency specifications. In addition, Infinity will transform the passenger experience by removing windows and including high definition screens along the interior walls of the cabin displaying the view outside the aircraft.

Benchmark Competitor Aircraft

Infinity will benchmark assumptions against the specification of 3 aircraft to calculate important basic parameters. The A380 will be used as this is the aircraft Infinity intends to replace. Boeing's 777 will be used as it will be one of the main competitors for Infinity. Boeing's 787-9 will also be used as inspiration for new technologies and material selection.

	Airbus A380-800	*Boeing B77-300ER*	*Boeing B787-9*
No. Engines	4	2	2
Thrust (kN/Eng)	311	436	320
Wing Span (m)	79.8	64.8	60.1
Wing Area (m²)	843	427.8	325
Capacity (Passengers-3 Class)	544	365	230
Max. Take-off Mass (kg)	560000	351500	251000
OEW/MTOW	0.495	0.477	0.441
MLW/MTOW	0.689	0.715	0.769

Table 1: *Benchmark aircraft key parameters*

Key Configuration Decisions

Figure 2 summarises some of the key configuration decisions being utilised by Infinity.

	Configuration	*Justification*
No. Engines	2	The industry is cracking down on CO_2 emissions and the noise pollution output of jet engines. The use of 2 engines instead of 4 will reduce these outputs significantly and make this aircraft more environmentally friendly. Furthermore, by using 2 engines the fuel efficiency is increased as well as maintenance costs being reduced. This leads to a cheaper operating cost (as well as the reduced standing cost in only purchasing 2 engines contrasted with 4). Finally using 2 engines as opposed to 4 will reduce the total wetted area thus resulting in a lower profile drag.
Fuselage type	Double-bubble	The increase in width over a single fuselage configuration means that the overall length of the aircraft can be reduced whilst retaining seat capacity. A double-bubble is beneficial over a double-decker configuration as jetways can be shorter. This is desirable over the A380 as the Infinity will be more airport compatible. Additionally, double-bubble configuration permits a more flexible cabin design with partitions. The distribution between economy and business/first class seating can be improved such that the economy capacity can be reduced (more chance that these seats will be filled), and business/first class capacity can be increased (a small increase in these classes results in a more profitable flight).
Wing type	Low mounted	A low mounted wing is more accessible for maintenance. Additionally, the spar locations will not interfere with the fuselage as much as a mid-mounted wing would. This wing location permits an improved under carriage mounting configuration as spars can be used for mounting, leading to improved ground manoeuvre stability.
Tail	Conventional	The conventional tail was selected due to the risks other configurations pose. A T-tail configuration was overlooked for Infinity due to the lack of controllability at high angles of attack as well as the increased probability of stall. A V-tail was overlooked as using this configuration leads to difficulties when trimming the aircraft.
Cabin Interior	Windowless	By removing the windows from the fuselage, the cabin walls have an improved structural integrity, whilst leading to a reduction in mass due to the lack of reinforcement required. (Recent Southwest Airlines' aircraft have shown windows to be a safety issue in the event of engine blade failure). Also, screening the outside on the interior of the cabin transforms the passenger experience and gives Infinity a unique selling point.

Table 2: *Key configuration decisions and justifications*

Three View Sketch

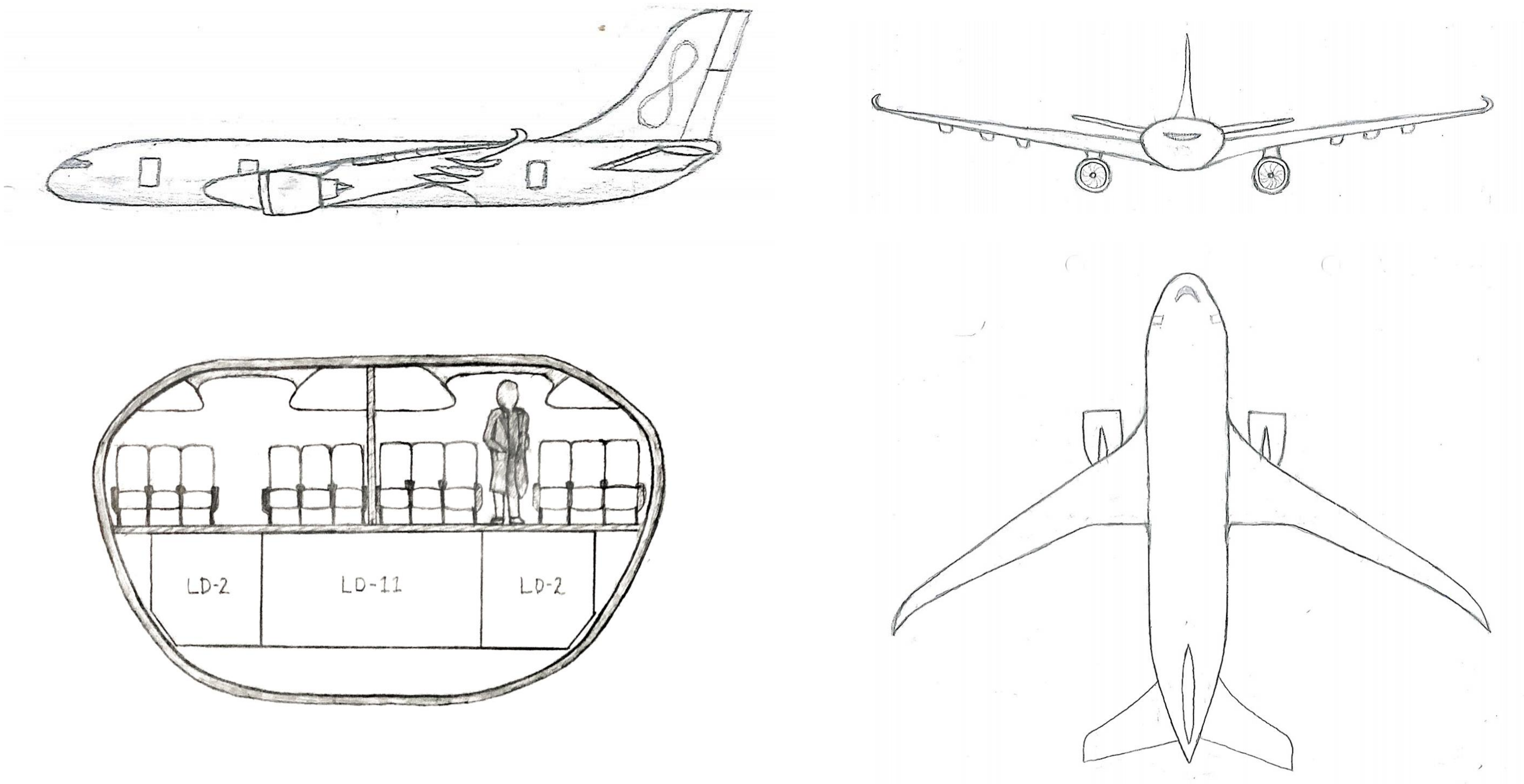


Figure 1: *Three view initial sketch and cabin cross section of Infinity*

Summary of Raw Key Data

In order to calculate the constraints, there needs to be an initial estimate of the overall size of this aircraft. This encompasses most general parameters such as wing dimensions, fuselage length, thrust and weight fractions. Finding initial estimates of these values can be achieved by using the benchmark aircraft to find plots relating certain known requirements. For example, the maximum take-off mass was initially found using a graph which related this parameter to number of passengers. This is done because the more passengers you transport, the heavier your aircraft will be. Figure 2 graphs this relationship for several different competitor aircraft and a trend line is subsequently plotted.

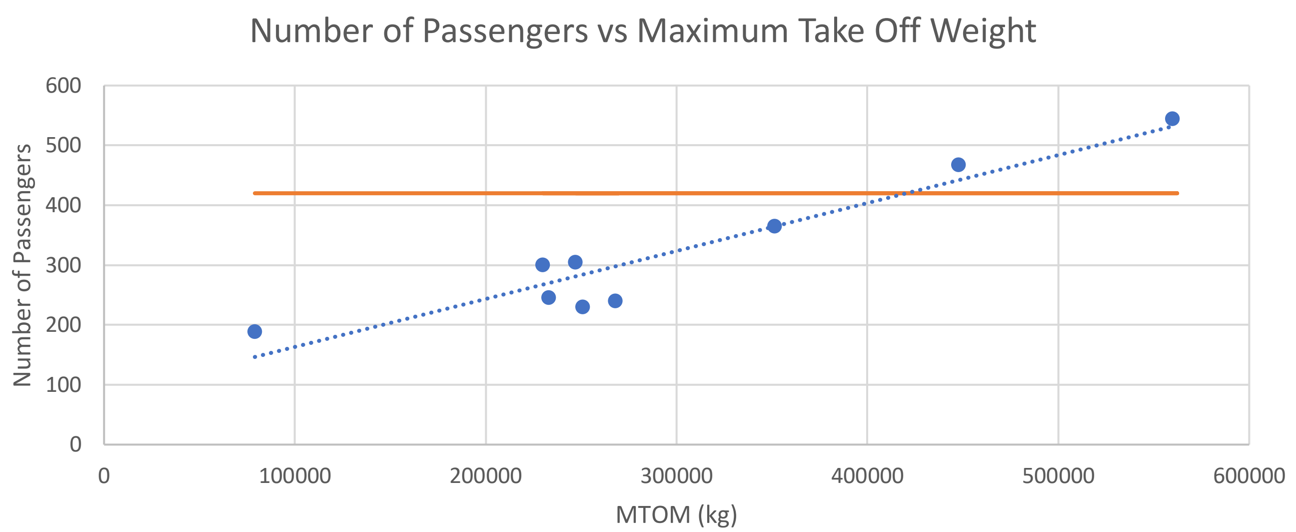


Figure 2: *Benchmark aircraft plots of PAX vs MTOM*

Infinity is tasked with carrying 420 passengers at its design capacity. Using the graph, 420 passengers can be mapped to a maximum take-off mass requirement of roughly 420 000kg. Once a maximum take-off mass was established, the initial wing parameters were estimated following a similar method. Using the benchmark aircraft, their maximum take-off masses were graphed against their respective wing areas and trend line plotted. See Figure 3.

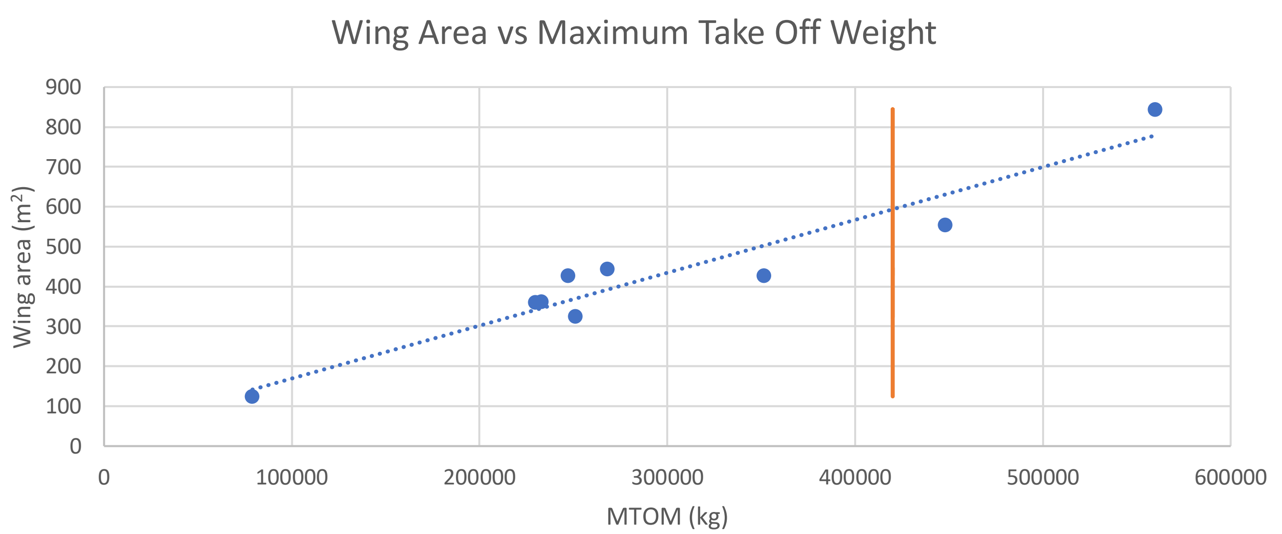


Figure 3: *Benchmark aircraft plots of wing area vs MTOM*

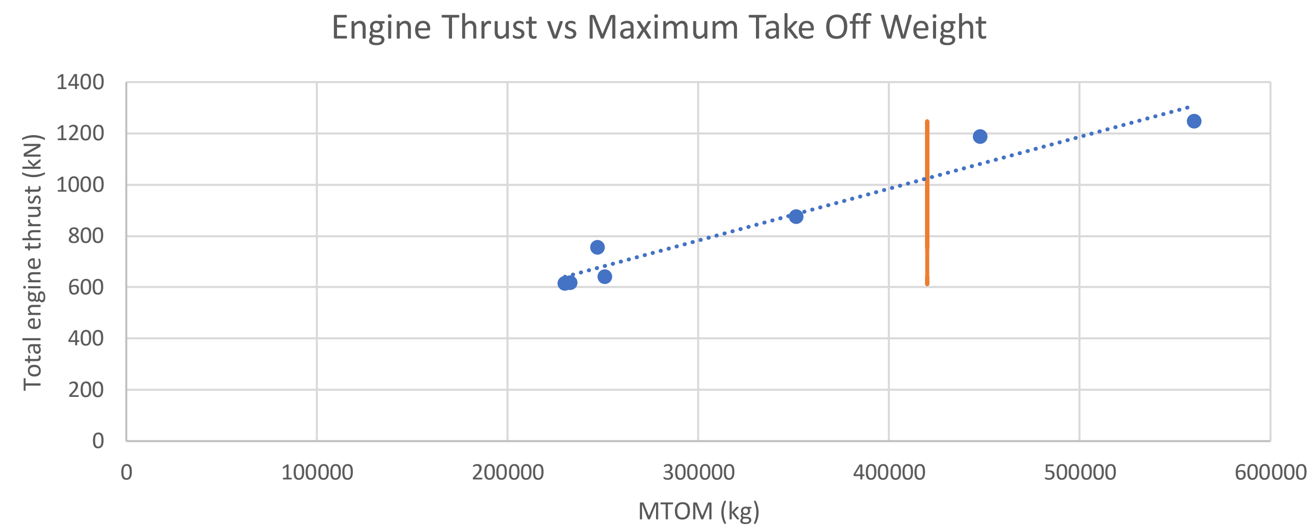


Figure 4: *Benchmark aircraft plots of total engine thrust vs MTOM*

Figure 3 estimates Infinity's total engine thrust to be roughly 1050kN. As previously stated, Infinity is striving for a twin-engine configuration and so this implies each engine will need to produce over 500kN of thrust each. Currently, the turbofan industry is limited and securing this calibre of engine is unlikely during the preliminary design stage of Infinity. As a result, an existing engine will be scaled to match our thrust requirement.

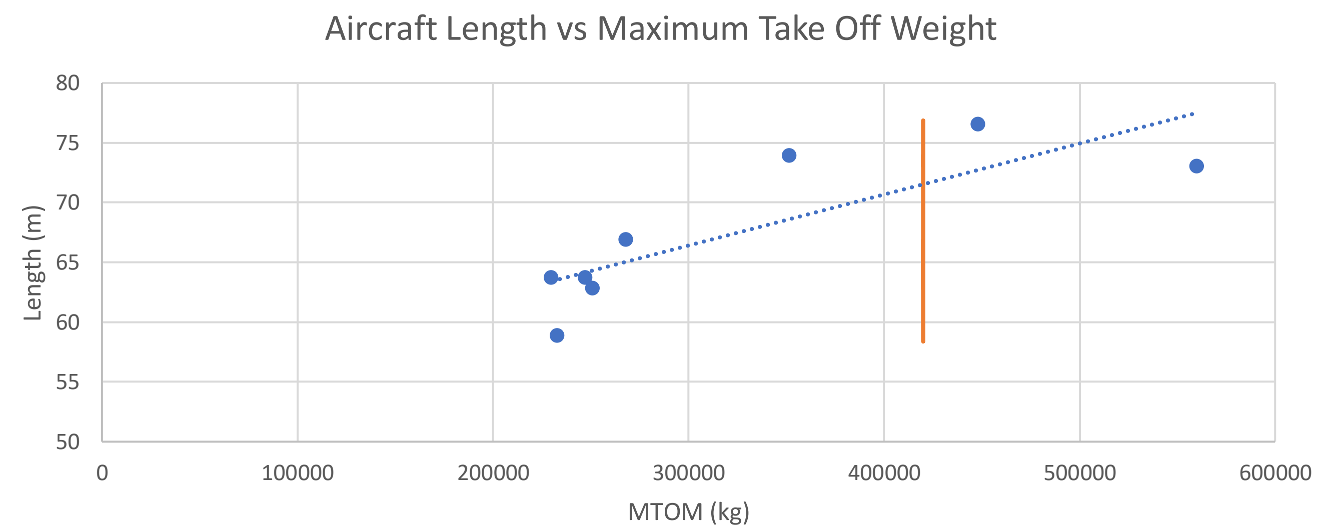


Figure 5: *Benchmark aircraft plots of length vs MTOM*

By using the trend-line and a plot for Infinity's MTOM, the fuselage length is found to be 72m. However, when considering fuselage length, it is important to consider factors in addition to maximum take-off mass. The double-bubble fuselage being incorporated on Infinity promotes shortening of the fuselage (as already discussed above in "Key Configuration Decisions"). This means that for a given MTOM it can be assumed that the length will be slightly shorter than single fuselage layouts, such as that found in the

787. For the purposes of this section, the greater value of length displayed by the graph will be chosen whilst a lower value in reality can be expected.

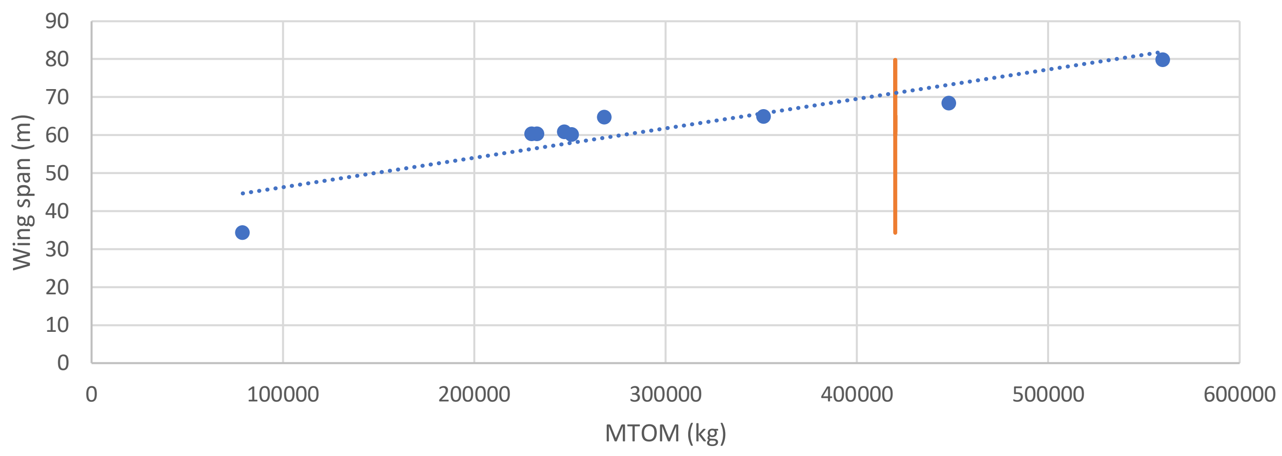


Figure 6: *Benchmark aircraft plots of wing span vs MTOM*

Similarly in finding wing area, the use of MTOM in determining wing span is important as the greater the weight of an aircraft is, the greater the lift requirement. Plotting 420000kg produces a wing span of roughly 70m.

Aspect ratio and Operational Empty Weight (OEW) are found by considering the Boeing 787-9. Firstly, the B787-9 has an aspect ratio of 10.03 according to research. The competitive nature of the industry implores new entries to the market to use a high aspect ratio around this value. For the purposes of this design stage, 11 has been chosen as the initial aspect ratio estimate.

Additionally, the B787-9 is a successful aircraft partly due to its material selection. Infinity will employ an almost 100% composite airframe and so the OEW can be assumed to drastically reduce in comparison with other aircraft. In keeping with B787-9 parameters, the weight fraction relating OEW to MTOW is chosen to be 0.4405.

Using this weight fraction, the Operation Empty Mass (OEM) of Infinity is initially calculated as 185 220kg. Table 3 gives a final summary of Infinity's initial key data.

Wing Area (m^2)	600
Wing Span (m)	70
Aspect Ratio	11
Fuselage Length (m)	70
MTOM (kg)	421 000
OEM (kg)	185 220
OEM/MTOM	0.4405
MLW/MTOM	0.7
Engine Thrust (kN)	1050

Table 3: *Summary of Infinity's initial raw key data*

Constraints

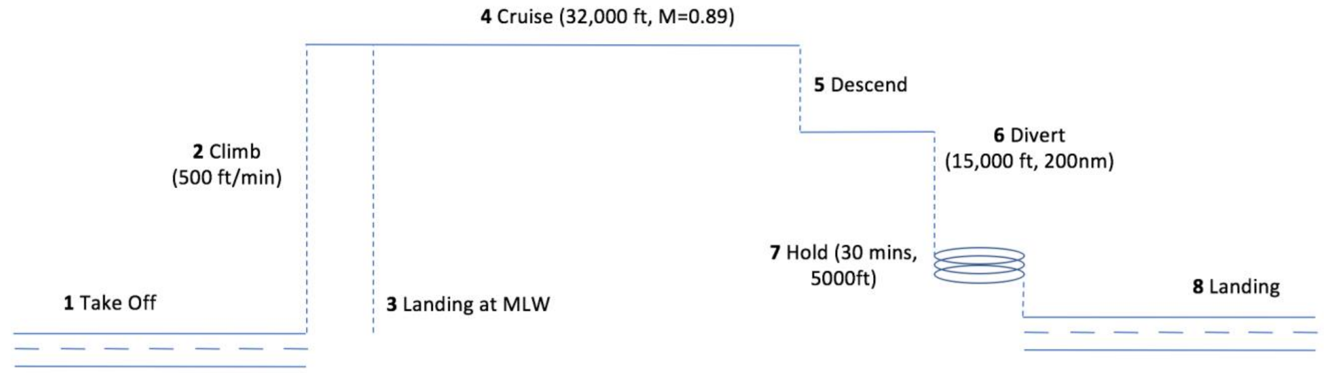


Figure 7: *Mission diagram showing constraint points*

First, the induced drag coefficient, k_1 must be defined. The Oswald efficiency factor for a straight and moderately swept wing with an aspect ratio of 11 is given by;

$$e = 1.78(1 - 0.045AR^{0.68}) - 0.64$$
$$e = 1.78(1 - 0.045 \times 11^{0.68}) - 0.64 = 0.730947038$$

As a result, the induced drag coefficient, k_1 is calculated as $\frac{1}{\pi eAR} = \mathbf{0.03958}$ which is used for all subsequent calculations.

TWO ENGINE OPERATIVE CASES

Constant Altitude and Speed Cruise
α = 0.203175 β = 0.85 C_{D0} = 0.015
Altitude = 32,000 ft M = 0.89

Wto/S	Tsl/Wto
1000	1.042230068
2000	0.536219457
3000	0.374262331
4000	0.298318575
5000	0.256780168
6000	0.232444435
7000	0.217938802
8000	0.209576981
9000	0.205311035

Constant Speed Climb (500 ft/min)
α = 0.21672 β = 0.975 C_{D0} = 0.015
Altitude = 32,000 ft M = 0.89 $\frac{1}{V}\frac{dh}{dt}$ = 2.54

Wto/S	Tsl/Wto
1000	0.815671667
2000	0.471725343
3000	0.376023621
4000	0.342383049
5000	0.333566938
6000	0.337163057
7000	0.347851878
8000	0.362973639
9000	0.381050693

Infinity will employ single slotted flaps however the performance of these is now equivalent to past double and triple slotted high lift systems. Hence 2D C_{Lmax} values for double slotted flaps and slats were used to find the following 3D C_{Lmax} values.

$$C_{maxLO} = 1.95467 \text{ and } C_{maxLAND} = 2.10503$$

Values for stall speed were derived from the approach speed (148 knots) which is assumed to be $1.3V_s$ = 58.57 m/s.

Take Off Ground Roll (FAR Length = 3100m)
α = 0.8261 β = 1.0 kLO = 1.2
Speed = $1.2V_s$ Ground Roll = 1953m

Wto/S	Tsl/Wto
1000	0.037997763
2000	0.075995525
3000	0.113993288
4000	0.151991051
5000	0.189988814
6000	0.227986576
7000	0.265984339
8000	0.303982102
9000	0.341979864

Landing Ground Roll (FAR Length = 2000m)
β = 0.7 kL = 1.15 Friction = 0.3
Speed = $1.15V_s$ Ground Roll = 1197.6m

Wto/S	Tsl/Wto
7133.92	0
7133.92	0.2
7133.92	0.4
7133.92	0.6
7133.92	0.8
7133.92	1
7133.92	1.2

ONE ENGINE INOPERATIVE CASES

For these conditions, the alpha values were halved to represent a one engine out case. Also, C_{D0} was assumed to be greater due to the wind-milling engine.

Constant Altitude and Speed Cruise
α = 0.22262 β = 0.975 C_{D0} = 0.0143
Altitude = 14,000 ft M = 0.5 L/D = 12

Wto/S	Tsl/Wto
1000	0.756655501
2000	0.400279034
3000	0.291243005
4000	0.244042085
5000	0.221575209
6000	0.211475354
7000	0.208442369
8000	0.209826178

Constant Speed Climb (0 - 35 ft)
α = 0.32714 β = 0.975 C_{D0} = 0.033
Speed = $1.2V_s$ $\frac{1}{V}\frac{dh}{dt}$ = 0.07028 L/D = 12

Wto/S	Tsl/Wto
1000 - 8000	0.257793017

Constant Speed Climb (35 – 400 ft)
α = 0.3943 β = 0.975 C_{D0} = 0.015 L/D = 12
Speed = $1.2V_s$ Altitude = 400ft $\frac{1}{V}\frac{dh}{dt}$ = 1.686

Wto/S	Tsl/Wto
1000	0.27218278

Stage 2 Approach
α = 0.26601 β = 0.75 C_{D0} = 0.103
Speed = $1.2V_s$ $\frac{1}{V}\frac{dh}{dt}$ = 0.021 L/D = 12

Wto/S	Tsl/Wto
1000	1.171412069
2000	0.585706325
3000	0.390471077
4000	0.292853453
5000	0.234282879
6000	0.195235829
7000	0.167345079
8000	0.146427017

Baulked Landing
α = 0.41306 β = 0.75 C_{D0} = 0.033
Speed = $1.2V_s$ $\frac{1}{V}\frac{dh}{dt}$ = 0.032 L/D = 12

Wto/S	Tsl/Wto
1000	0.24170358
2000	0.12085207
3000	0.08056824
4000	0.06042632
5000	0.04834117
6000	0.0402844
7000	0.03452957
8000	0.03021345

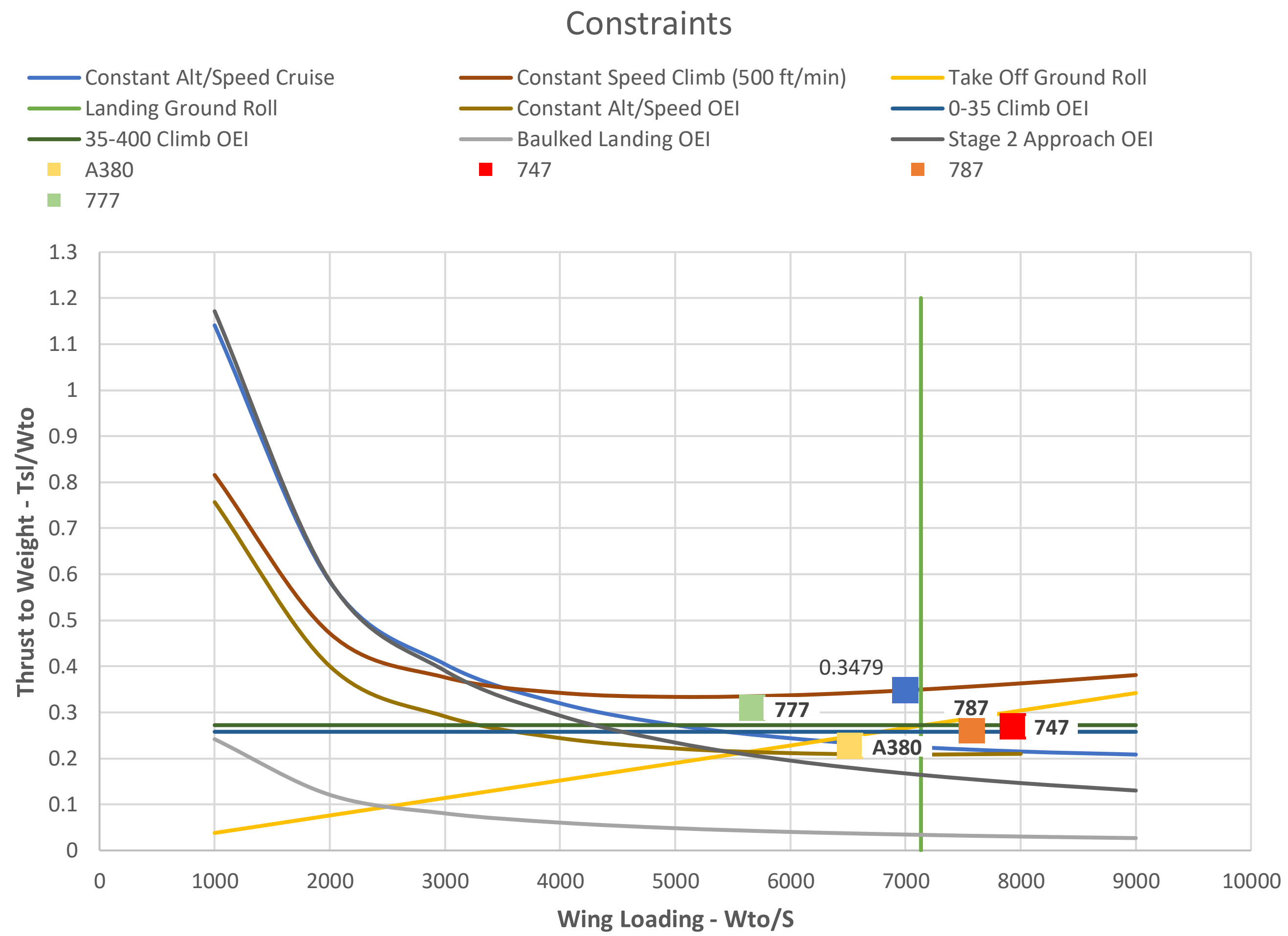


Figure 8: *Constraints diagram*

From the constraints diagram, the main constraining lines are Constant Speed Climb (500 ft/min) and Landing Ground Roll. These two values are restricted by JAR/FAR Part 25 requirements such as runway field lengths and airline requirements for take-off and traffic control adjustments. According to the plot, the closest know point is 0.3479. It was decided this value could be increased to 0.352 to give a design margin. Comparing this value to existing aircraft, the thrust to weight is higher than the A380, 777, 747 and 787. This explains the high thrust values required for the engines. Wing loading is also higher than the comparison aircraft which can be attributed to the higher assumed C_{Lmax} value.

Mission Diagram

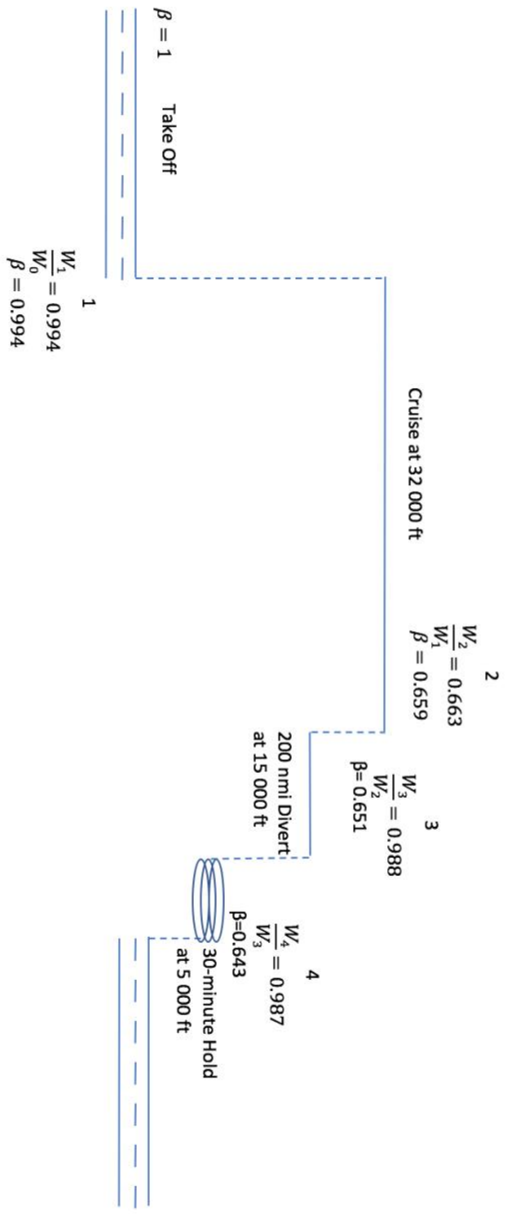


Figure 9: *Mission Diagram*

Mission Sizing Estimates

Parameter	Estimated Value
TSFC (Cruise)	0.52 N/N/Hr
$(L/D)_{Max}$	20.52
$(L/D)_{Cruise}$	17.77
Optimum Cruise Speed	255.95 m/s
Optimum Endurance Speed	217.74 m/s
Design Payload	46 250 kg
Design Take Off Weight (Final)	320 524 kg
Engine Thrust (Final)	553.4 kN per engine (1106.8 kN total)
Wing Area (Final)	449.2 m^2
Wing Span (Final)	70.32 m
Operational Empty Weight Fraction (W_{OEW}/W_{TO})	0.4405
Fuel Fraction (W_F/W_{TO})	0.4152
Fuel Volume (including ullage)	171 345 litres

Table 4: *Summary of key Mission Sizing Parameters*

Segment	Take Off	Cruise	Divert	Hold
Weight Fraction	0.994	0.663	0.988	0.987

Table 5: *Summary of weight fractions for each segment*

TSFC

The value of TSFC was estimated from existing engine data. It was assumed that Infinity would utilise a high bypass ratio turbofan engine and the GE-9X was used as a benchmark engine to scale the aircraft's engines against. The GE-9X has a bypass ratio of 10:1 which is identical to what Infinity will employ. Therefore, using competitor engines a value of TSFC was estimated as 0.52 N/N/Hr.

L/D

$(L/D)_{Max}$ was found from the following equation:

$$\left(\frac{L}{D}\right)_{Max} = \frac{1}{2\sqrt{k_1 C_{D0}}}$$

$(L/D)_{Cruise}$ was then found as 86.6% of $(L/D)_{Max}$. Cruise lift to drag ratio is lower than the maximum lift to drag ratio as the product of velocity and L/D is optimised instead to give the best range conditions.

Optimum Cruise Speed

The aircraft was designed so its required cruise speed would be equal to its optimum speed. Requirements state that this should be at M=0.85 at 32 000 ft which was found to be 255.95 m/s via an ISA table.

Optimum Endurance Speed

To find optimum endurance speed, optimum cruise speed was divided by 1.31 in order to maximise lift to drag ratio.

Design Payload

The Design Payload was determined from the mission requirements. It was determined as follows; firstly, passenger mass was calculated. Assuming a standard 3 class layout with 420 passengers:

$$75\ kg/PAX = 75 \times 420 = 41\ 250\ kg$$

Added to the bulk cargo requirements (5 tonnes), the design payload was then obtained:

$$Payload = 41\ 250 + 5\ 000 = 46\ 250\ kg$$

Weight Fractions and Design Take Off Weight

To calculate the design take-off weight of Infinity, first the fuel fraction of the aircraft was calculated. The fuel fraction was determined from the worst-case mission seen in the mission diagram. The calculation is shown below:

Firstly, the weight fraction at the end of take-off was calculated using the following equation:

$$\frac{W_1}{W_0} = e^{-\Delta t\left(TSFC\left(\frac{\alpha}{\beta}\right)\left(\frac{T_{SL}}{W_{TO}}\right)\right)}$$

Δt is the duration of take-off (120 seconds) and beta is the weight fraction at the beginning of the segment (1). Substituting in values to the above expression yields a weight fraction of 0.994. Next, the maximum cruise requirement weight fraction was calculated. This range was defined from mission requirements as 7006 nmi (12 974 450 m). Climb is neglected as the additional fuel burn during climb can be assumed to be negligible during the first weight fraction iteration. The cruise weight fraction calculation is shown below and uses the Breguet Range equation at 32 000 ft and M=0.85:

$$\frac{W_2}{W_1} = e^{\left(-\left(\frac{R}{V}\right)\left(\frac{TSFC}{L/D}\right)\right)}$$

Substituting in numerical values obtains a weight fraction for segment 2 of 0.663. To calculate the required fuel fraction. The worst-case mission is then flown, this equates to a 200 nmi (370 400 m) divert and a 30-minute hold before landing. Divert is calculated at 15 000 ft and also uses the Breguet Range equation at M=0.85 yielding a weight fraction for segment 3 of 0.988.

The hold weight fraction is then calculated at 5 000 ft using the Breguet Endurance equation shown below:

$$\frac{W_4}{W_3} = e^{\left(-(E)\left(\frac{TSFC}{L/D}\right)\right)}$$

Assuming optimum endurance speed and an endurance time of 30 minutes (1 800 seconds) yields a weight fraction of 0.987. From the above weight fractions the zero-fuel weight fraction of the aircraft can then be defined by multiplying all the segment weight fractions and adding 10% cruise reserves. This is seen below:

$$\frac{W_{ZF}}{W_{TO}} = \frac{W_1}{W_0} \times \left(\frac{W_2}{1.1W_1}\right) \times \frac{W_3}{W_2} \times \frac{W_4}{W_3}$$

Substituting numerical values yields:

$$\frac{W_{ZF}}{W_{TO}} = 0.994 \times \frac{0.663}{1.1} \times 0.988 \times 0.987 = 0.585$$

From the zero-fuel weight fraction, the fuel weight fraction can be found as seen below:

$$\frac{W_F}{W_{TO}} = 1 - \frac{W_{ZF}}{W_{TO}} = 1 - 0.585 = 0.415$$

The operational empty weight was then estimated from competitor aircraft, namely the 787-9 due to its modern structure and composite design. The OEW fraction was estimated as 0.4405. The MTOW was then calculated using the equation seen below:

$$W_{TO} = \frac{W_{PL}}{\left(1 - \frac{W_F}{W_{TO}} - \frac{W_{OE}}{W_{TO}}\right)} = 3\ 144\ 342\ N = 320\ 524\ kg$$

Wing Area, Span and Engine Thrust

From the MTOW and the design point found from constraints, wing area, span and engine thrust can be easily found. Wing area is found by:

$$S = W_{TO} \div \frac{W_{TO}}{S}$$

Substituting in numerical values yields a wing area of 449.2 m^2. The 70.32 m wing span was then found via:

$$b = \sqrt{\frac{S}{AR}}$$

Finally, engine thrust was found by multiplying the design thrust to weight ratio by the MTOW of the aircraft yielding a total 1106.8 kN of thrust.

Fuel Volume

The required volume of fuel to fly the worst-case mission was calculated from the fuel fraction and is shown below:

$$V_F = \frac{W_F}{W_{TO}} \times W_{TO} \times \frac{1.03}{g\rho_{fuel}}$$

Where ρ_{fuel}=0.8 kg/l and 3% is included for ullage giving a fuel volume of 171 345 litres.

__Figure 20:__ 3D CAD render

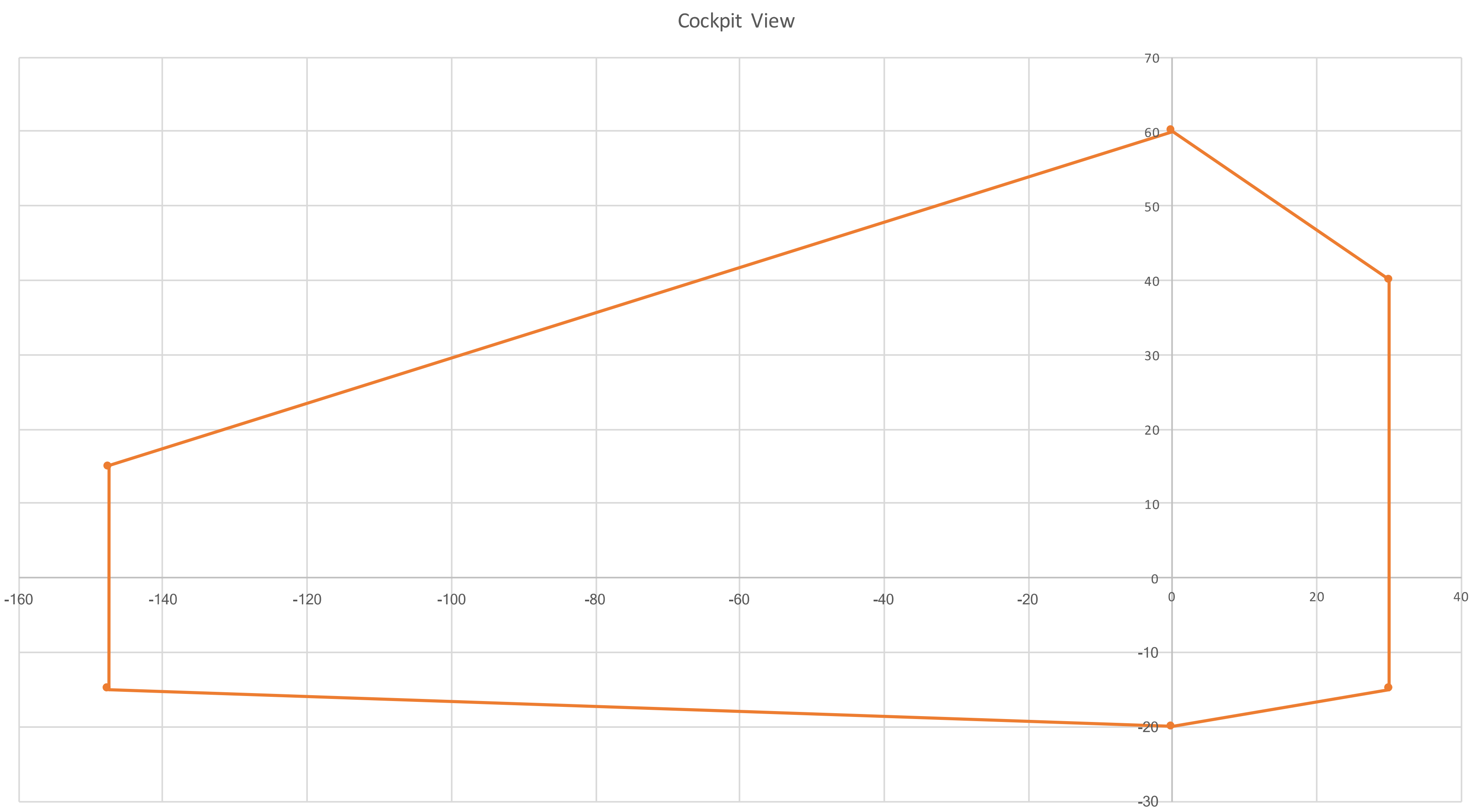


__Figure 11:__ Cockpit view plot§

Mean Aerodynamic Chord Calculation

Mean Aerodynamic Chord (MAC) is calculated by splitting the wing into two trapezoidal sections. These sections are separated by the break extending out from the root. The area of these two sections are denoted by S1 and S2 respectively and their MACs are given by MAC_1 and MAC_2.

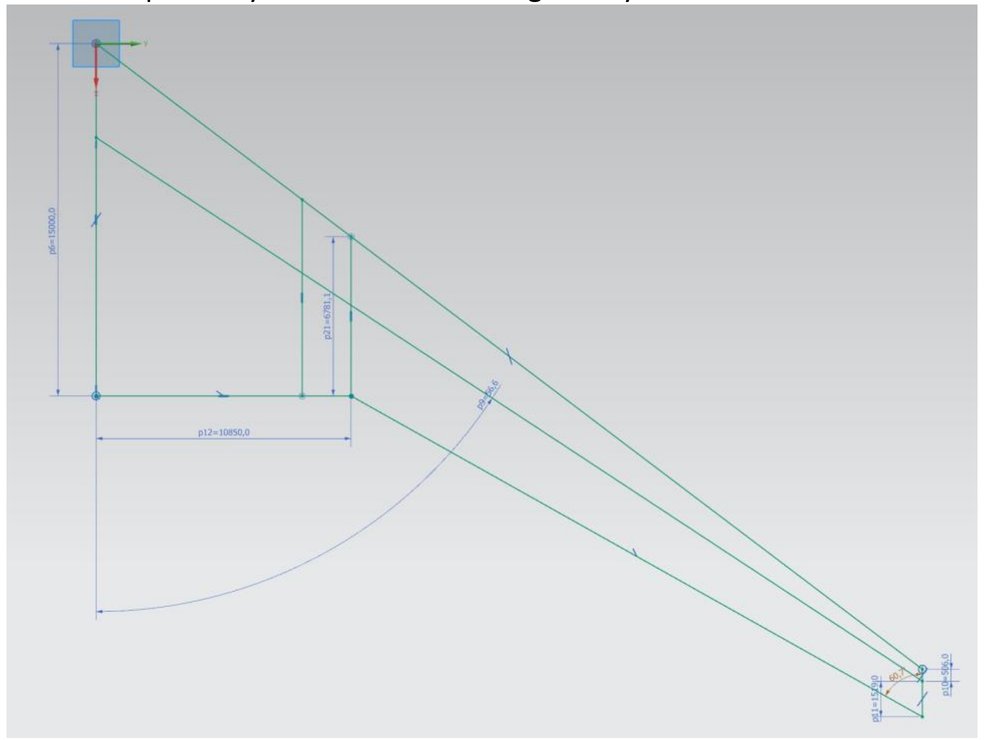


Figure 12: *Half wing planform – used to calculate mean aerodynamic chord*

.

MAC 1:

$$\lambda = \frac{c_{break}}{c_r} = \frac{6.78}{15} = 0.452$$

$$MAC_1 = \frac{1+\lambda+\lambda^2}{1+\lambda}\frac{2}{3}c_r = \frac{1+0.452+0.452^2}{1+0.452}\times\frac{2}{3}\times 15 = 11.4m$$

$$y_{MAC_1} = \frac{break}{2}\frac{1+2\lambda}{3(1+\lambda)} = \frac{10.85}{2}\times\frac{1+2\times 0.452}{3(1+0.452)} = 2.37m$$

$$x_{MAC_1} = y_{MAC_1}\tan\Lambda_{LE} = 2.37\times\tan 37.144 = 1.796m$$

MAC 2:

$$\lambda = \frac{c_t}{c_{break}} = \frac{2.025}{6.78} = 0.299$$

$$MAC_2 = \frac{1+\lambda+\lambda^2}{1+\lambda}\frac{2}{3}c_{break} = \frac{1+0.299+0.299^2}{1+0.299}\times\frac{2}{3}\times 6.78 = 4.83m$$

$$y_{MAC_2} = \frac{halfspan - break}{2}\frac{1+2\lambda}{3(1+\lambda)} + \text{break} = \frac{35.16-10.85}{2}\times\frac{1+2\times 0.299}{3(1+0.299)} + 10.85 = 15.834m$$

$$x_{MAC_2} = y_{MAC_2}\tan\Lambda_{LE} + (c_r - break) = 15.83\times\tan 37.144 + (15-10.85) = 11.999m$$

$$S_1 = \frac{1}{2}(c_r + c_{break})\text{break} = \frac{1}{2}(15+6.78)\times 10.85 = 118.16m^2$$

$$S_2 = S_{\frac{1}{2}span} - S_1$$

$$S_2 = 225.2 - 118.16 = 107.04m^2$$

The mean aerodynamic chord is given by:

$$MAC = \frac{S_1 MAC_1 + S_2 MAC_2}{S_1 + S_2}$$

$$MAC = \frac{118.16\times 11.4 + 107.04\times 4.83}{225.2} = 8.277m$$

$$y_{MAC} = \frac{S_1 y_{MAC_1} + S_2 y_{MAC_2}}{S_1+S_2}$$

$$y_{MAC} = \frac{118.16\times 2.37 + 107.04\times 15.834}{225.2} = 8.77m$$

$$x_{MAC} = \frac{S_1 y_{MAC_1} + S_2 x_{MAC_2}}{S_1+S_2}$$

$$x_{MAC} = \frac{118.16\times 1.796 + 107.04\times 11.999}{225.2} = 6.646m$$

Component	Mass (kg)	Location
Max. Take-off	320524.1301	Centre of Gravity: 36.04m
Wing	32052.41301	40% MAC
Main Landing Gear	11218.34455	35% MAC
Fuselage & Systems	57487.79531	45% Fuselage Length
Nose Gear	1923.144781	10% Fuselage Length
Tail	4807.861951	90% Fuselage Length
Engines	22246.84651	-10% MAC
Propulsion	28506.34195	-10% MAC
Nacelle	5194.978225	-10% MAC

Wing Total	76972.07774	
Fuselage Total	64218.80204	

Table 6: *Mass location breakdown for each component*

Wing Location Calculation

$$x_{wing,\%MAC} = \frac{0.4 + 0.35 - 0.1 - 0.1}{76972.07774} = 0.152$$

$$x_{fuselage,cg\%fuselagelength} = \frac{0.45 + 0.1 + 0.9}{64218.80204} = 0.473$$

$$x_b = 0.25 + \frac{76972.07774}{64218.80204}(0.25 - 0.152) = 0.368$$

$$x_b = 0.25 + \frac{76972.07774}{64218.80204}(0.25 - 0.152) = 0.368$$

$$x_{b_{MAC}} = 0.368 \times 8.277 = 3.05m$$

$$x_{fuselage,ABScg} = 71.2 \times 0.473 = 33.69\text{m}$$

$$Apex = x_{fuselage,ABScg} + x_{b_{MAC}} - 8.77 = 27.98m$$

Costs and Emissions

Costs

To calculate the cost of Infinity, first standing costs must be calculated; these are defined as costs independent of flight time and are all calculated using 2017 prices. These costs are shown below:

$$Airframe \ @ \ \$1403.69 \ /kg: 1403.69 \times 141190.879 = \$198.188M$$

Where 141 190.879 kg is the OEW weight of the aircraft.

$$Engine \ @ \ \$50.13 \ /N: 50.13 \times 1\ 106\ 808 = \$55.484M$$

Where 1 106 808 N is the thrust produced by both engines. The cost of spares was estimated at 6% of the airframe cost and 25% of the engine cost.

$$Total\ standing\ cost = 1.06 \times 198.188 + 1.25 \times 55.484 = \$279.435M$$

Next, investment costs were calculated. Investment costs are comprised of interest costs, insurance costs and depreciation costs. Depreciation cost was found assuming the aircraft's value would fall to 12.5% of its total standing cost after 16 years leading to a reduction of $15.282M/year. Using an interest rate of 4%, the cost for Infinity was calculated at $11.177M/year (4% of total standing cost). Insurance was estimated as 0.35% of total standing cost and was found to be $887 854/year. Total investment cost was then calculated as a sum of insurance, interest and depreciation costs giving:

$$Investment\ Cost = 15.282 + 11.177 + 0.888 = \$27.347M/year$$

Assuming a flying time of 4 800 hours per year gives:

$$27.347 \times 10^6 \div 4800 = \$5\ 697/hour$$

Next, the flying costs were calculated. The costs were based on the longest mission flight defined as 15 hours, this was found from cruise time plus 25 minutes (the flight time was rounded up to the next hour). Firstly, crew costs were calculated as seen below:

$$Flight\ Crew\ (2) @ \ \$1423.75\ /hour: 1423.75 \times 15 = \$21\ 356/flight$$

Assuming a minimum of 1 cabin crew member for every 50 passengers (9 members):

$$Cabin\ Crew\ @\ \$180.47\ /hour/person = 180.47 \times 15 \times 9 = \$24\ 363/flight$$

Next, landing fees were calculated assuming a maximum landing weight equivalent to 70% of the MTOW:

$$Landing\ Fees\ @\ \$12.03\ /tonne: 12.03 \times 320\ 524 \times 0.7 = \$2\ 699/flight$$

Navigation costs were calculated as:

$$Navigation\ Costs = \frac{Stage\ length}{5}\left(\frac{MTOM}{50}\right)^{0.5} \times Flight\ Duration \times Inflation = \$13\ 206/flight$$

Ground handling costs are split into two categories; cargo costs and passenger costs. The calculation can be seen below:

$$Cargo\ Cost\ @\ \$220.58\ /tonne: 220.58 \times 5 = \$1\ 103/flight$$
$$Passenger\ Cost\ @\ \$16.79\ /PAX: 16.79 \times 420 = \$7052/flight$$

Maintenance costs are also divided into two categories; airframe maintenance and engine maintenance. These costs were calculated as follows:

$$Airframe\ Maintenance = (175 + 4.1M_{OE}) \times Flight\ Duration \times Inflation = \$18\ 772/flight$$
$$Engine\ Maintenance = 0.29T \times Flight\ Duration \times No.Engines \times Inflation = \$7\ 992/flight$$

Finally, fuel cost was calculated at two prices, $2/US Gallon and $4/US Gallon. This gave the following fuel costs:

$$Fuel\ Cost\ @\ \$2/\ US\ Gallon: 2 \times 23\ 194 = \$46\ 389/flight$$
$$Fuel\ Cost\ @\ \$4/\ US\ Gallon: 4 \times 23\ 194 = \$92\ 777/flight$$

Parameter	Cost ($)
Airframe	198.188M
Engine	55.484M
Airframe Spares	11.891M
Engine Spares	13.871M

Depreciation	15.282M/year
Insurance	887 854/year
Interest	11.177M/year
Flight Crew	21 356/flight
Cabin Crew	24 363/flight
Landing Fees	2 699/flight
Navigation Costs	13 206/flight
Cargo Costs	1 103/flight
Passenger Costs	7502/flight
Airframe Maintenance	18 772/flight
Engine Maintenance	7 992/flight
Fuel @ $2/US Gallon	46 389/flight
Fuel @ $4/US Gallon	92 777/flight
Hourly Operating Cost	4 652/hour
Hourly Maintenance Cost	1 784/hour

***Table 7**: Cost model inputs*

DOC Metric	$2/US Gallon	$4/US Gallon
Stage	$228 391	$279 779
Km	$17.60	$21.18
Seat km	4.19₵	5.04₵

***Table 8**: DOC metrics*

Emissions

CO_2 emissions were calculated for both required flights, London (Heathrow) to Singapore (6 765 mi) and Hong Kong to New York (John F Kennedy) (8 702 mi). CO_2 emissions were found as 3.15 times the fuel mass required. Fuel mass was found from take-off and cruise weight fractions for each mission. CO_2 emissions for each mission can be seen below:

$$CO_2\ Emissions, LHR - SIN: 94\,314 \times 3.15 = 297\,090 kg$$
$$CO_2\ Emissions, JFK - HKG: 109\,204 \times 3.15 = 343\,993 kg$$

CO_2 emissions per seat km per passenger are then calculated by:

$$CO_2\ Emissions/km/passenger = \frac{343\,993}{12\,974.45 \times 420} \times 1000 = 63.12\ g/km/PAX$$

Viability

Weight fractions calculated as part of the mission sizing are justified by a number of factors. The incorporation of a fully composite airframe will result in a much OEW than the Airbus A380 since the A380 is comprised of only 22% composites. The main reason why the OEM/MTOM for Infinity is similar to that of the 787-9 is because of its material selection.

In addition to this, the lower MTOM of Infinity is further justified by the decrease in engines from 4 to 2. Incorporating this whilst maintaining a high passenger capacity of 420 justifies Infinity being heavier than a 787 but lighter than an A380.

The double-bubble fuselage is a relatively new addition into the aircraft industry. Infinity not only benefits from its increase in width for capacity reasons, but also yields a more elliptical lift profile than singular tubed fuselages. This increase in lift over the fuselage would accommodate a reduction in wing area thus resulting in a lower profile drag; however this lift benefit was not considered in the calculation of Infinity's parameters.

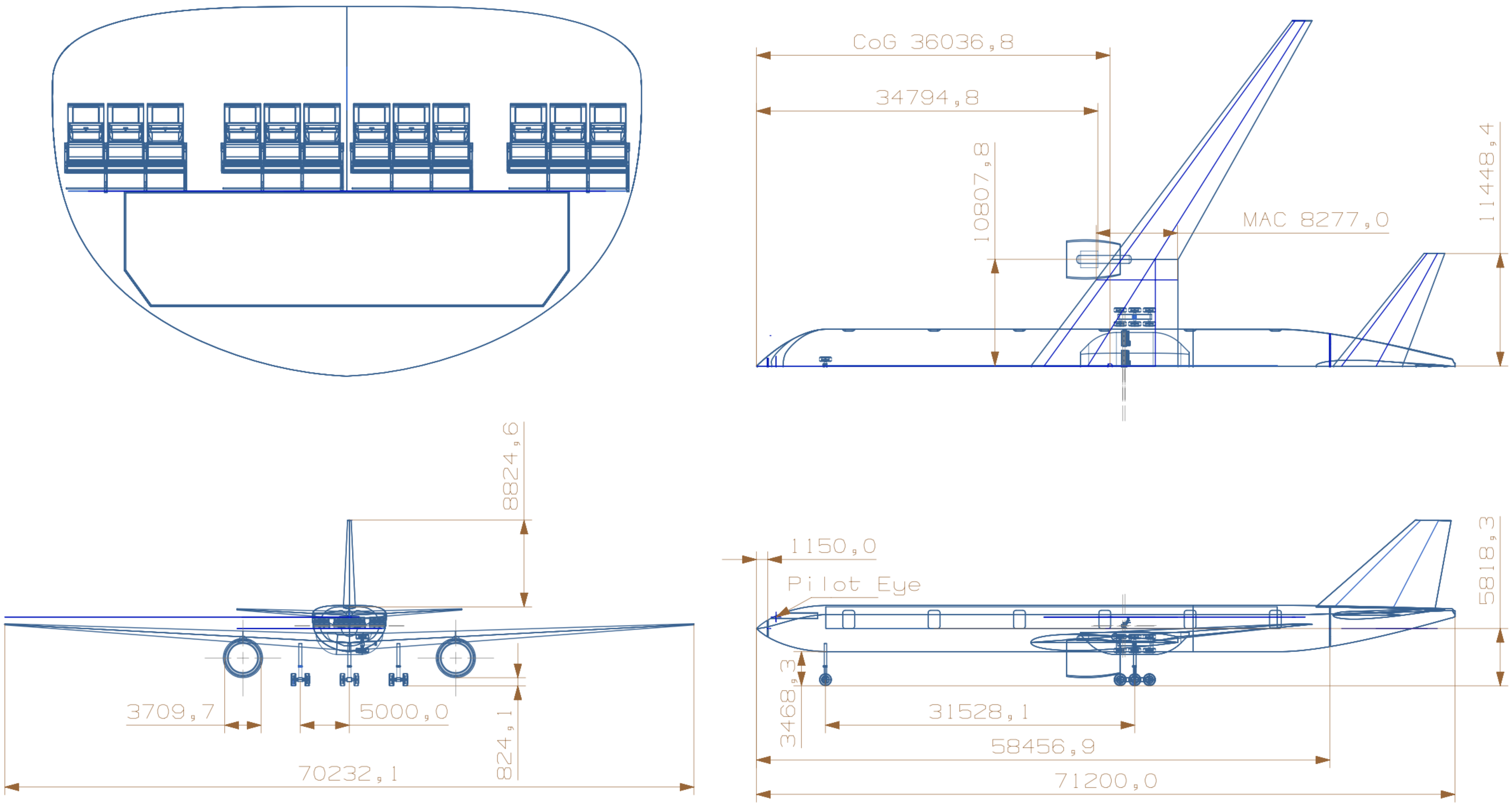
Exclusion of the windows for Infinity is crucial for the noise reduction within the cabin as well as weight reduction. Without windows, there is no need for window reinforcements thereby saving weight. Structural integrity of the fuselage is improved with reduced cut-outs along the length. External noise is also minimised with fewer weak spots to pass through. The engine exhausts are positioned beneath the wing meaning noise is deflected downwards away from the fuselage and passengers.

The use of a high aspect ratio, slender wing was one of the fundamental design decisions for Infinity. This was driven by the A380's significantly oversized wing which produces large amounts of induced drag vastly decreasing the fuel efficiency of the aircraft. By employing an aspect ratio of 11, there is improved aerodynamic performance and drag reduction. The shorter chord means skin friction is minimised due to lower Reynold's numbers. Not only this, but wingtip vortices are considerably less than those seen on the A380 such that the induced drag is reduced. However, a large aspect ratio leads to a reduced fuel wing box volume meaning some fuel must be stored in the tail. In addition, the wing loading is increased compared to competitor aircraft meaning the stresses on main wing structural components (spar, stringers, ribs etc.) rise.

There are some areas which would require improvement with further development. Firstly, it would be beneficial to reduce the amount of fuel stored in the vertical tail plane. This is because with fuel in the tail plane, the aircraft will require more trimming throughout the flight as fuel is burnt. Secondly the cockpit layout resulting from the aircraft configuration is far from conventional. The windows are wider than normal which could affect structural integrity. Additionally, modifications to the conventional cockpit would be required to accommodate the increase in width between pilots.

Regarding noise pollution, Infinity attempts to meet requirements with the following configuration choices. Firstly, with an increased aspect ratio, the chord is shorter resulting in a lower vorticity. Secondly, Infinity employs 2 high bypass engines complete with rear chevrons. The high bypass stems from an increase in fan flow reducing the noise produced by the engine as a result of reduced mixing. In using 2 fewer engines compared with the A380, combined with the higher bypass ratio, the noise output of Infinity is drastically minimised. Finally, the incorporation of a single slotted flap system leads to a reduction noise over more complex high lift configurations.

To close, the design considerations for Infinity make it a very appealing replacement for the A380. From the double bubble design to the high aspect ratio slender wing, this aircraft proves it is possible to create an efficient high capacity airliner without compromise. Low operating costs as well as low fuel consumption make for a far more cost effective aircraft. Overall, Infinity is a better aircraft for passengers, airlines and the high capacity aircraft industry as a whole.



Wing Area	450.2 m2	Front Spar	0.15c
Wingspan	70.23 m	Main Spar	0.65c
Fuselage Length	71.2 m	Kick Spar	0.85 x Cr
CoG Loc. (x,z)	36.04 m, 5.818 m	Root Chord	15 m
Tailscrape (Static)	11 deg	Tip Chord	2.025 m
Tailscrape (Unloaded)	14 deg	HZ Tail Area	105.16 m2
Wingtip Scrape	9 deg (engine)	VT Tail Area	62.22 m2
Engine Diameter	3.7 m	Engine Thrust	553 kN / engine
Turnover Angle	49.3 deg	LE Sweep	37.1 deg