Final Report

Course: MAE 159 - Aircraft Performance

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Winter 2025 specifications:

Number of passengers (2-class, domestic rules)	210
Weight of cargo (10 pounds/ft^3) Maximum Payload Weight 55,000 lbs	8000 pounds
Range (still air)	3500 nautical miles
Takeoff field length (sea-level, hot day 84° f)	6900 feet
Landing approach speed	135 knots
Cruise Mach number	0.80
Initial cruise altitude	35,000 feet
Maximum wingspan	125 feet
Maximum landing weight with 45% fuel	

Engine Configuration: 2 JT9D-class engines, wing-mounted

Seating Layout: 6 abreast

Wing Design: Taper ratio = 0.35

Date: March 1st, 2025

1. Approach

In this study, commercial transport conventional aircraft design and advanced technology aircraft design are compared for economic performance. Both designs have to satisfy all the specifications requirements and safety requirements while keeping Direct Operating Cost (DOC) as low as possible.

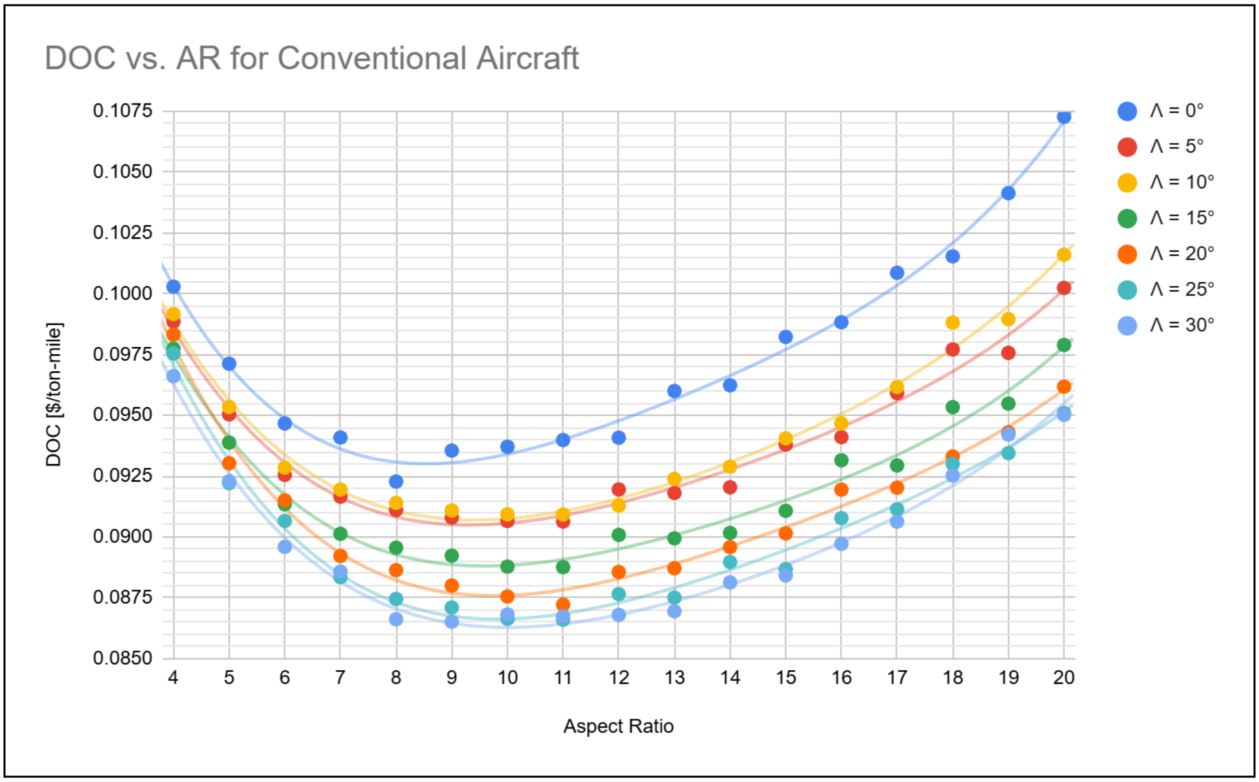
1.1 Design Specifications

Specification	Value
Number of Passengers	210 (2-class, domestic rules)
Cargo Weight	8,000 lbs (10 lbs/ft^3)
Maximum Payload Weight	55,000 lbs
Range (still air)	3,500 nautical miles
Takeoff Field Length	6,900 feet (sea-level, hot day 84°F)
Landing Approach Speed	135 knots
Cruise Mach Number	0.8
Initial Cruise Altitude	35,000 feet
Maximum Wingspan	125 feet
Maximum Percent Fuel Weight at Landing	45%

Table 1: Aircraft Design Specifications

Table 1 shows the specifications that the two aircrafts are required to meet. These design parameters define the aircraft's operational capabilities, including passenger and cargo capacity, cruise range, takeoff field length, landing performance, and other aerodynamic constraints. Besides these explicit specifications, the two aircrafts also have to meet all safety requirements such as minimum 1.3 stall velocity operation and passing safety gradients in all flight segments. Optimization is performed by parallelly clearing all requirements and iterating aspect ratio (AR) and swept angle (Λ) for minimum DOC. Other properties of the aircraft are then extracted and calculated from the MATLAB code for further sizing procedure and final design in Solidworks. This process is done twice for the conventional aircraft design and the advanced technology design.

1.2 Wing Sizing Results



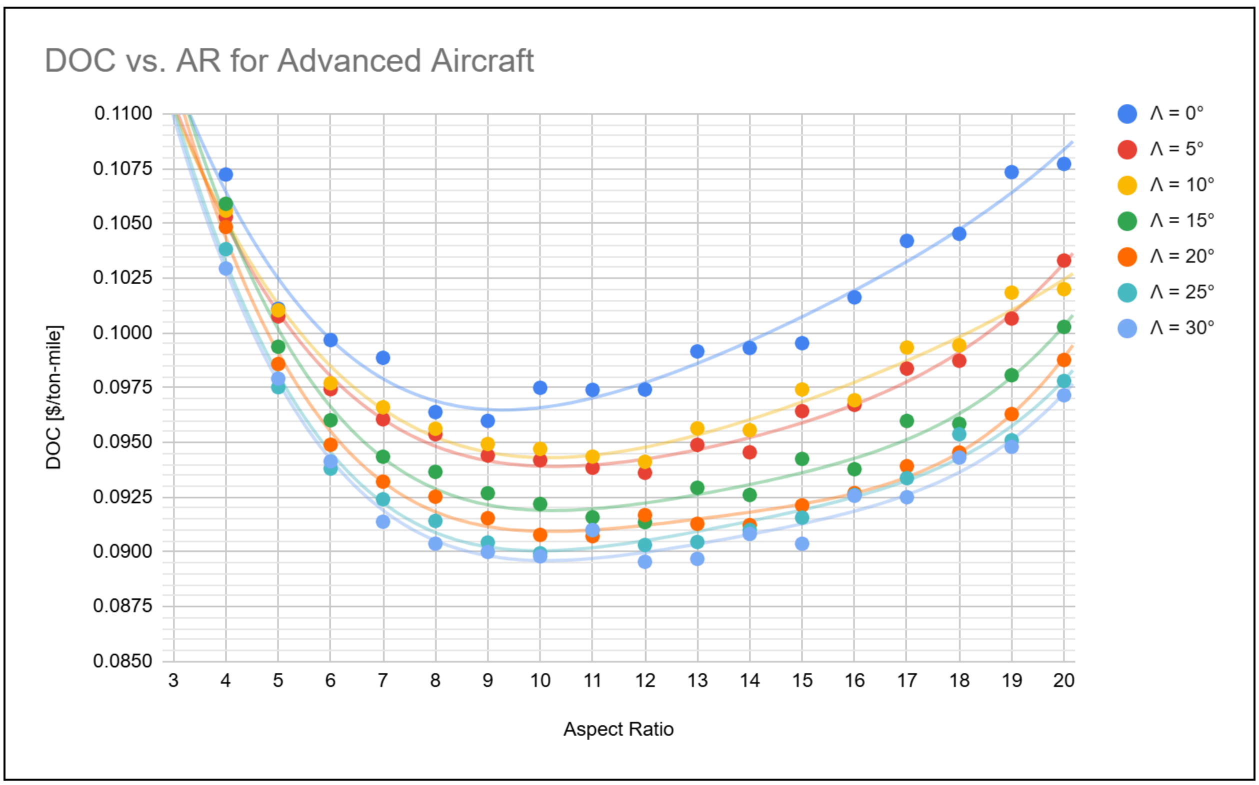
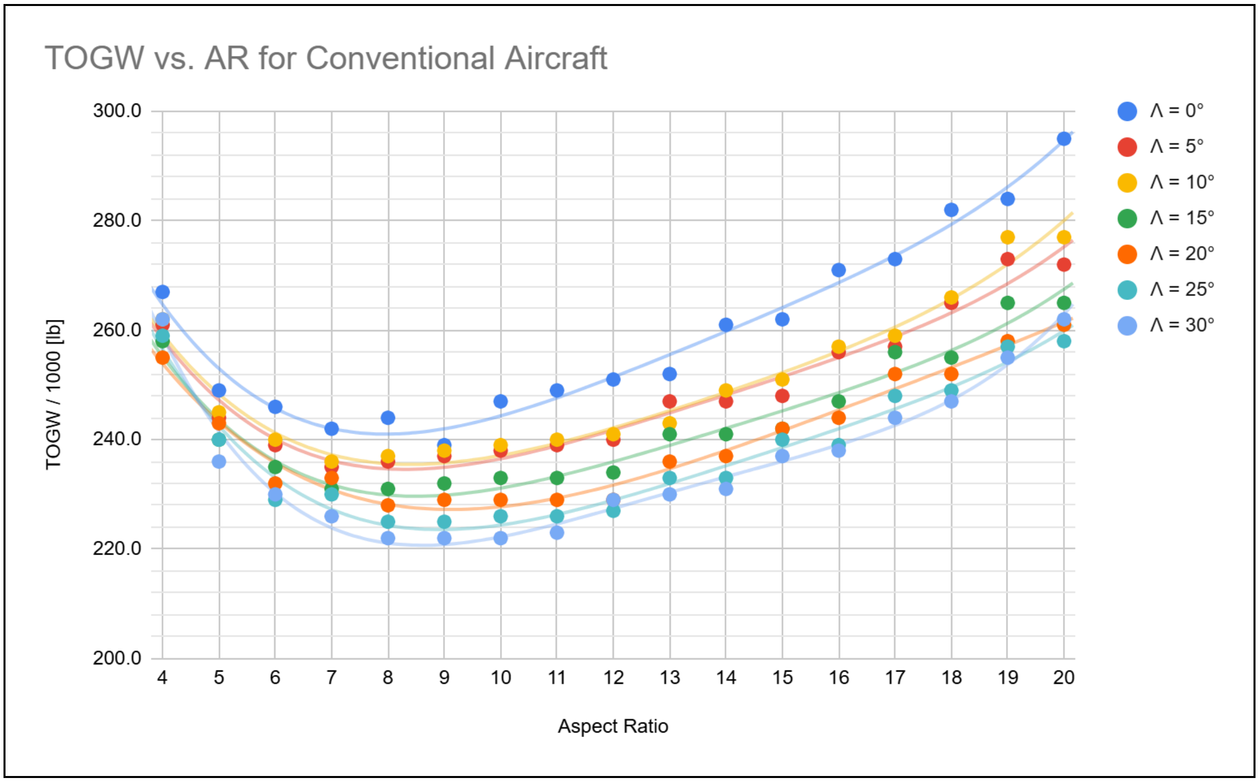


Figure 1: DOC vs. AR for All Aluminum (top) and for All Composite (bottom)



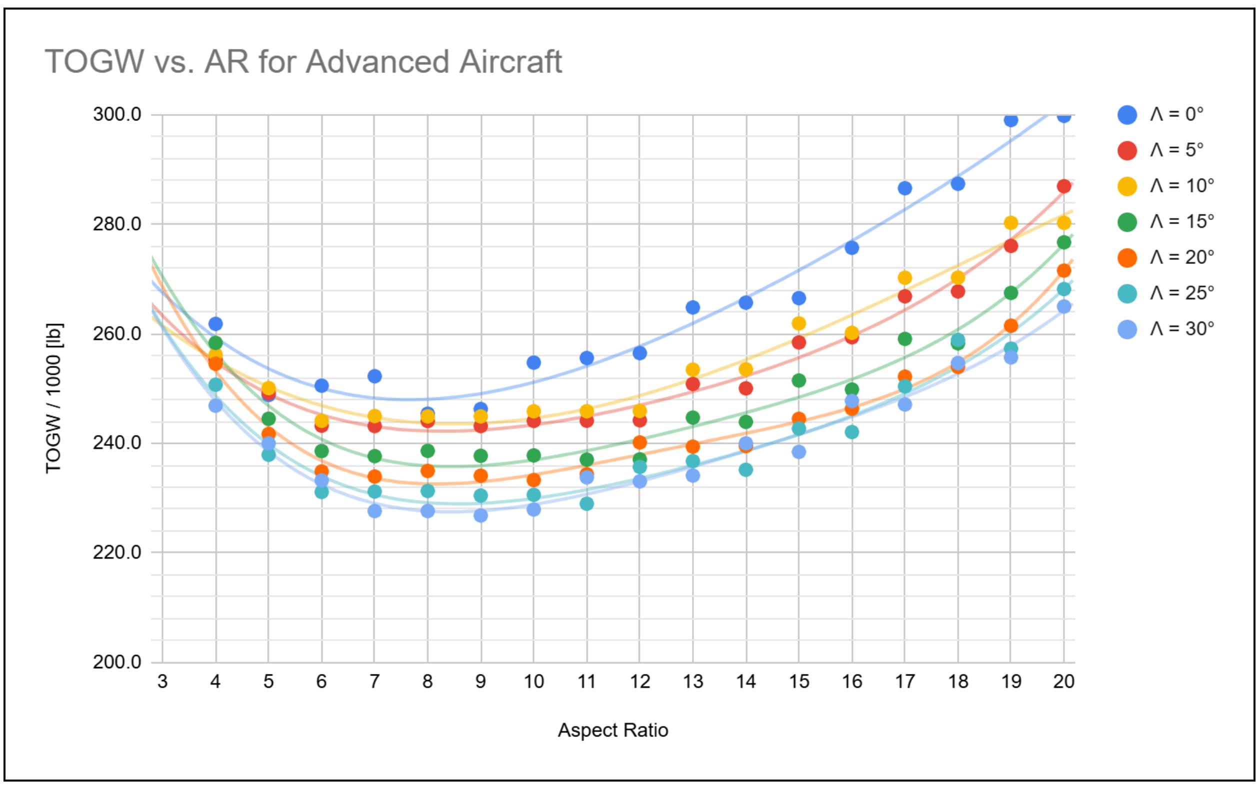


Figure 2: TOGW vs. AR for All Aluminum (top) and for All Composite (bottom)

It's worth noting that both DOC vs. AR graphs and TOGW vs. AR graphs converge at the same AR and Λ. Therefore, minimizing DOC is the same as minimizing Takeoff Gross Weight (TOGW). This makes sense because TOGW and DOC have a linear relationship. As TOGW increases, DOC increases and as TOGW decreases, DOC also decreases.

Aspect ratio trend is in U shape. At extreme low AR, 4, and extreme high AR, 20, the DOC is significantly higher than mid range AR, 7-11. The AR that gives the lowest DOC is around 9, which is expected for most current commercial aircrafts [1]. However, due to the Maximum Wingspan requirement in Table 1, AR is chosen to be 8. At AR value at 9 and above, the wingspan is greater than 125 [ft], thus disqualifying them from design consideration.

Swept angle trend is opposite to DOC. As Λ increases, DOC decreases. Therefore, Λ should be as high as possible to minimize DOC. However, when Λ is too high, the designs cannot pass all specifications and safety requirements. This leads to Λ stops at 30° for both designs because higher Λ values aren't able to pass safety gradients.

1.3 Primary Analysis: Detailed Composite vs Aluminum

WEIGHT [lb]	**Conventional**	**Advanced**
Wing	22,077.63	22,559.16
Fuselage	2,542.66	2,557.72
Nacelle + Pylon	4,661.90	4,842.47
Tail	4,342.67	4,437.39
Power Plant	23,463.19	25,809.51
Fixed Equipment	37,630.00	37,827.83
Fuel	64,994.09	72,136.82

Table 2: Components Weight Comparison Between Conventional and Advanced Designs

Specific fuel consumption (SFC) for conventional aircraft design is 0.68 while SFC for advanced aircraft design is 0.61 because advanced engines provide a 10% decrease in SFC.

In conventional aircraft design, all components are in aluminum while in advanced aircraft design, all components are in composite material. In particular, wing and tail components weight decrease 30%, fuselage weight decreases 15%, fixed equipment weight decreases by 10%, nacelles and pylons decrease by 20%.

FOR COMPOSITE STRUCTURE –

(WING + TAIL) × .70

(FUSELAGE) × .85

(FIXED EQUIP – CREW) × .9

(NACELLES & PYLONS) × .8

Figure 3: Course Manual Advanced Technology Weight Change

The only exception is the power plant because for advanced technology, the power plant weight is 10% higher to trade off for the 10% decrease of the SFC. Composite material is lighter than aluminum, so theoretically advanced aircraft design should have lower weight compared to conventional aircraft design. However, because of the increase in power plant weight and decreases in SFC, the design optimization loop changed the configuration into a different optimal TOGW thus changing the weight of all components.

1.4 Aircraft Comparison Specs

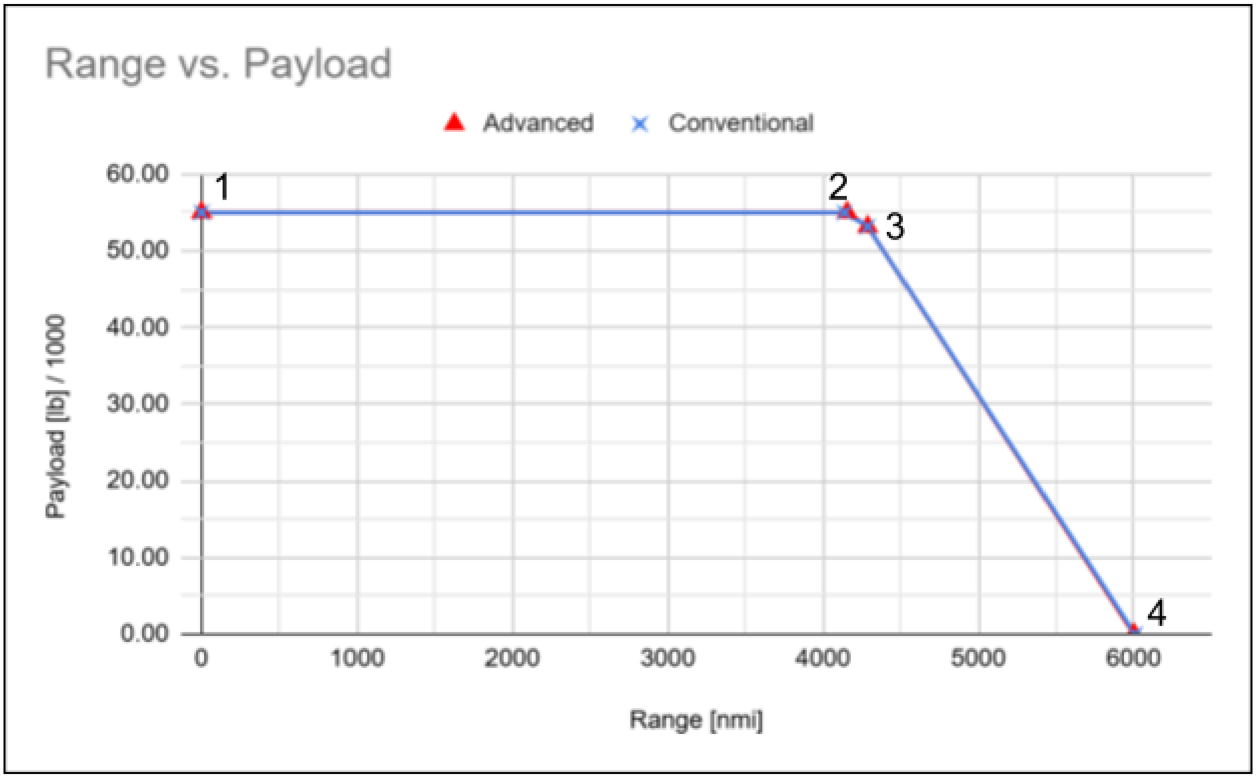
	Conventional	Advanced
WING		
Wingspan [ft]	123.02	122.40
MAC [ft]	16.57	16.48
Planform Area [ft^2]	1,891.67	1,872.76

Airfoil Type	Supercritical	Supercritical
Aspect Ratio (AR)	8	8
Swept Angle (°)	30	30
FUSELAGE		
Length [ft]	165.78	165.78
Diameter [ft]	14	14
Seats Abreast	6	6
MATERIAL		
Wing	Aluminum	Composite
Fuselage	Aluminum	Composite
Nacelle + Pylon	Aluminum	Composite
Tail	Aluminum	Composite
Fixed Equipment	Aluminum	Composite
WEIGHT [lb]	**Conventional**	**Advanced**
Wing	22,077.63	22,559.16
Fuselage	2,542.66	2,557.72
Nacelle + Pylon	4,661.90	4,842.47
Tail	4,342.67	4,437.39
Power Plant	23,463.19	25,809.51
Fixed Equipment	37,630.00	37,827.83
Fuel	64,994.09	72,136.82
ENGINES		
Flat Plate Drag Area [ft^2]	30.77	30.60
Engine Type	JT9D	JT9D
Number of Engines	2	2
Max Thrust per Engine [lb]	43,857.47	44,154.67
Takeoff Gross Weight [lb]	222,000.00	227,652.24
All-out Range NM	4,045.84	4,045.84

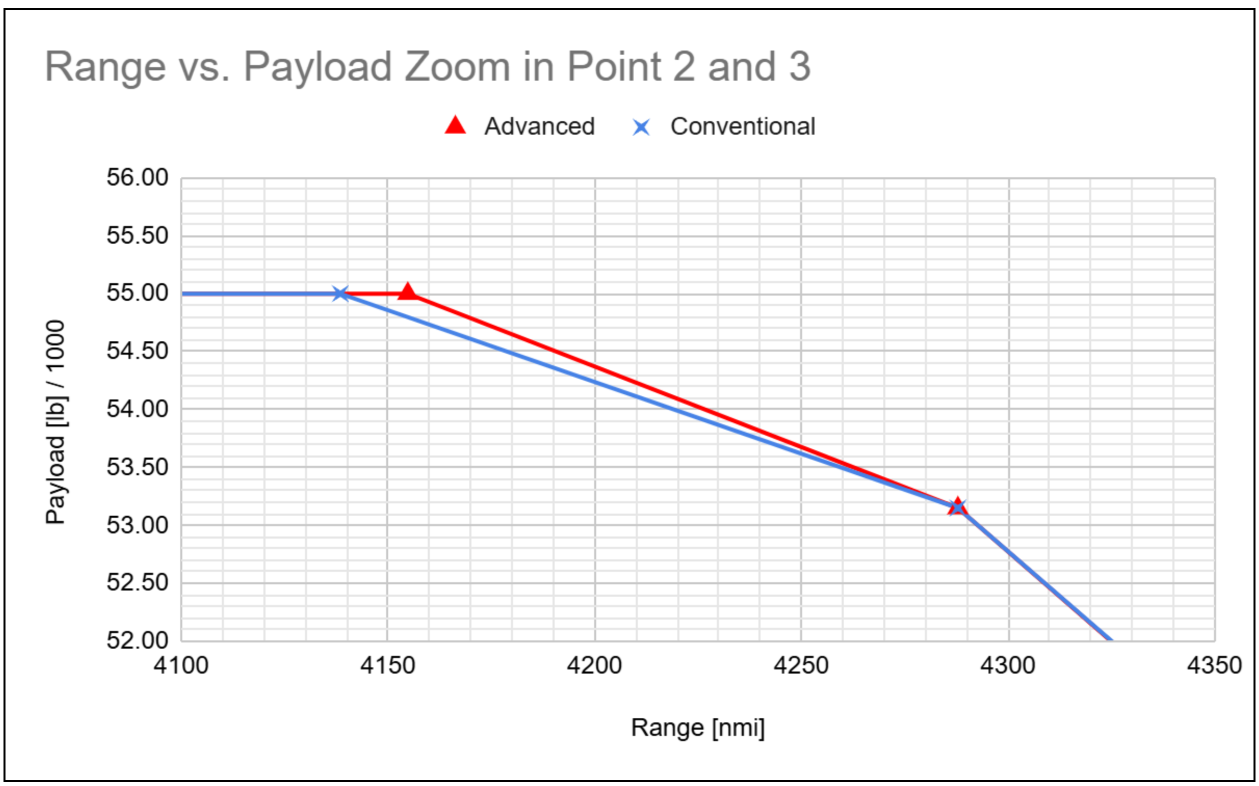
DOC [$/ton-mile]	0.0865	0.0900
SFC	0.68	0.61
Powerplant Weight [lb]	24,501.38	26,951.52

Table 3: Specification Comparison Between Conventional and Advanced Designs

The comparison between the conventional (full aluminum) and advanced (full composite) aircraft designs reveals a nuanced balance of performance, efficiency, and economic considerations. Both configurations use a supercritical airfoil with similar wing dimensions, maintaining an aspect ratio (AR) of 8 and a swept angle of 30 degrees. This consistency ensures aerodynamic efficiency is primarily determined by structural materials rather than geometric differences. The full composite wing, though slightly heavier (22,559.16 lb) than the aluminum wing (22,077.63 lb), may offer better durability and reduced life-cycle maintenance. The small increase in weight might reflect enhanced structural integrity offered by composites. Both configurations employ JT9D engines, but the advanced design achieves slightly higher thrust per engine (44,154.67 lb vs. 43,857.47 lb). This reflects the ability of composite materials to endure greater stress, possibly enhancing propulsion efficiency. The composite design, with its sophisticated material technology, results in higher fuel capacity (72,136.82 lb vs. 64,994.09 lb) to potentially expand operational range under heavier payloads. However, this benefit comes with an increased Direct Operating Cost (DOC) of $0.0900/ton-mile compared to the aluminum design's $0.0865/ton-mile. This suggests that while composites offer performance improvements, they might slightly elevate operational expenses without significant cost-offsetting measures.



Range vs. Payload
Advanced
Conventional
Payload [lb] / 1000
Range [nmi]
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
1000
2000
3000
4000
5000
6000
1
2
3
4



Range vs. Payload Zoom in Point 2 and 3
Advanced
Conventional
Payload [lb] / 1000
Range [nmi]
56.00
55.50
55.00
54.50
54.00
53.50
53.00
52.50
52.00
4100
4150
4200
4250
4300
4350

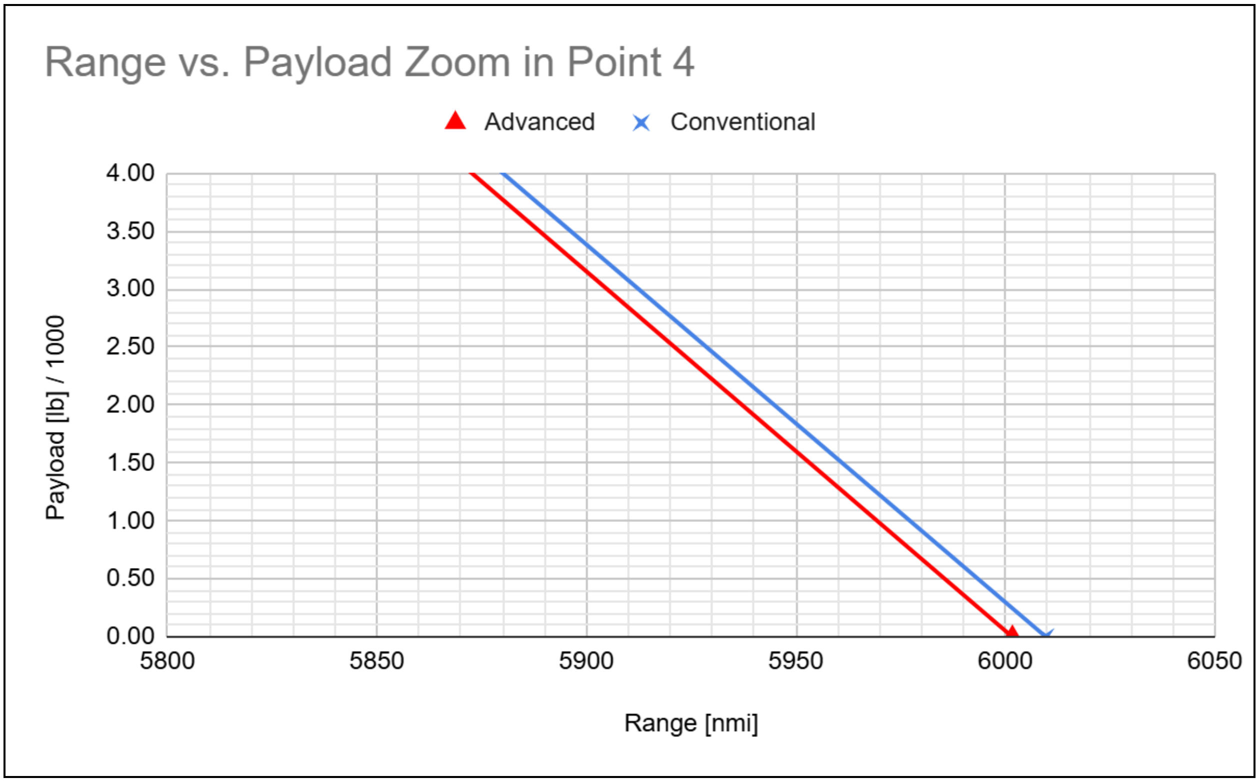


Figure 4: Payload Range Chart

2. Results and Conclusions

After a thorough analysis and comparison of the conventional aluminum and advanced composite configurations, the decision is made in favor of the full aluminum configuration. This choice is based on a combination of efficiency, cost-effectiveness, and familiarity that aligns well with operational and strategic goals.

Aluminum has a long history in the aerospace industry, providing proven reliability and durability. The material's known performance characteristics reduce the risk associated with adopting new technologies and support consistent operational outcomes. The production and material costs for aluminum are markedly lower than those for advanced composites. This results in substantial savings upfront, allowing airlines to allocate resources to other critical areas such as training, maintenance, and expansion. Aluminum's extensive use means simplified maintenance procedures and a wide availability of repair expertise and parts. This leads to reduced maintenance downtimes and costs throughout the aircraft's lifecycle, enhancing overall operational efficiency.

DOC for conventional aircraft is lower compared to advanced aircraft. Therefore, by continuing with aluminum, airlines capitalize on a well-understood material while remaining competitive in markets dominated by cost-sensitive decisions. This choice also supports a conservative risk profile, appealing to stakeholders prioritizing stability and predictability.

3. Description of the Configuration

3.1 Wing and Tails

Wing AR, Λ, and reference area (S_{ref}) is taken from MATLAB code and analysis above. In AR vs. DOC Figure 1 and Figure 2, the lowest points are chosen for the two aircrafts. Then using equations in Schaufele textbook, the rest of the information of the wing can be calculated.

Name	Value / Equation
⊟ Global Variables	
"Root Chord W"	= 2 * "S_ref" / ("Span W" * (1 + "Taper Ratio W"))
"Tip Chord W"	= "Root Chord W" * "Taper Ratio W"
"Swept Angle W"	= 30
"Span W"	= sqr ("S_ref" * "AR W")
"AR W"	= 8
"S_ref"	= 1872.75746643
"Taper Ratio W"	= 0.35
"MAC W"	= (2 / 3) * "Root Chord W" * (1 + "Taper Ratio W" - ("Taper Ratio W" / (1 + "Taper Ratio W")))
"Y W"	= ("Span W" / 6) * ((1 + 2 * "Taper Ratio W") / (1 + "Taper Ratio W"))

Table 4: Equations for Wing in Solidworks

Here the calculation was computed inside Solidworks Equations so that they can be directly implemented in the 3D design as variables. In later design and sizing processes, when these parameters need to be changed, they can be changed easily and updated systematically in Solidworks to smooth out the design process.

For tail sizing, Schaufele is heavily utilized. Tail Volume was determined from the graphs in Fig. 6-9 and 6-15 of Schaufele. This value is then double checked in Tables of Fig. 6-10 and 6-16. Schaufele Fig. 6-17 and 6-18 are used to determine the AR and Taper Ratio (λ) for the tails. These values are a good first estimation of tails. For actually accurate values, however, course MAE 175 offers a more detailed analysis for flight dynamics stability and sizing procedure for tails to keep the aircraft stable during flight.

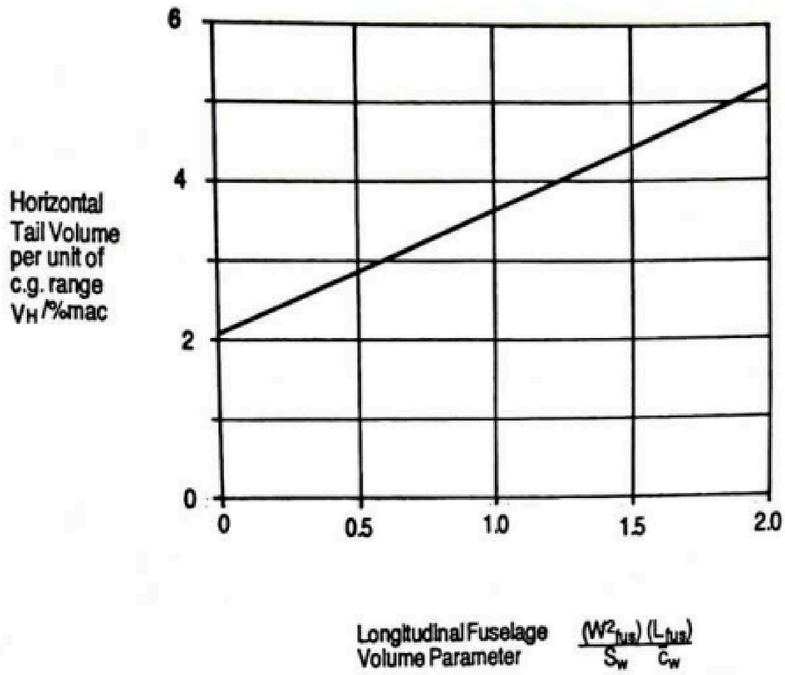


Fig. 6-9 Preliminary Design Chart ~ Horizontal Tail Volume Determination

Aircraft Type	V_H Range
Personal/Utility	.48- .92
Commuters	.46-1.07
Regional Turboprops	.83-1.47
Business Jets	.51 - .99
Jet Transports	.54-1.48
Military Fighter/Attack	.20 - .75

Fig. 6-10 Representative Horizontal Tail Volume Ranges

Figure 5: Fig. 6-9 and 6-10 from Schaufele for Horizontal Tail Volume

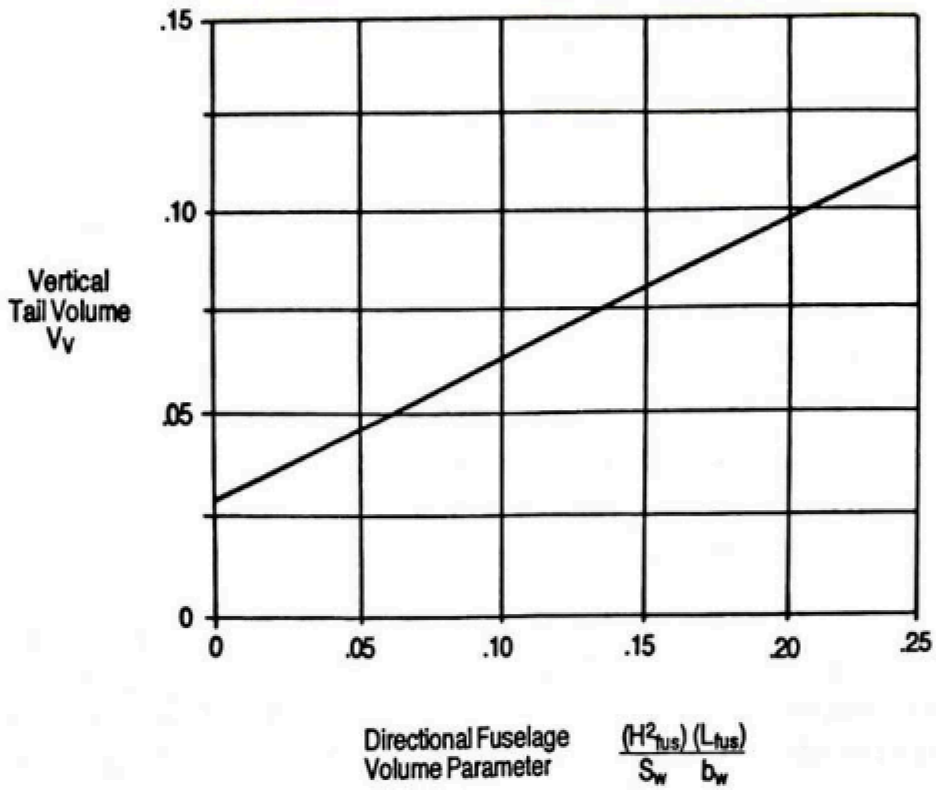


Fig. 6-15 Preliminary Design Chart ~ Vertical Tail Volume Determination

Aircraft Type	V_V Range
Personal/Utility	.024 - .086
Commuters	.041 - .097
Regional Turboprops	.065 - .121
Business Jets	.061 - .093
Jet Transports	.038 - .120
Military Fighter/attack	.041 - .130

Fig. 6-16 Representative Vertical Tail Volume Ranges

Figure 6: Fig. 6-15 and 6-16 from Schaufele for Vertical Tail Volume

Aircraft Type	AR	λ	c_e/c	t/c
Personal/Utility	3.5-5.0	.50-1.0	.35-.45	.06-.09
Commuters	3.5-5.0	.50-.80	.35-.45	.06-.09
Regional Turboprops	3.5-5.0	.50-.80	.30-.45	.06-.09
Business Jets	3.5-5.0	.35-.50	.30-.40	.06-.09
Jet Transports	3.5-5.0	.25-.45	.30-.35	.06-.09
Military Fighter/Attack	3.0-4.0	.25-.40	.30-1.0	.03-.04

Fig. 6-17 Summary of Horizontal Tail Geometric Characteristics

Aircraft Type	AR	λ	c_r/c	t/c
Personal/Utility	1.2-1.8	.30-.50	.25-.45	.06-.09
Commuters	1.2-1.8	.30-.80	.35-.45	.06-.09
Regional Turboprops	1.4-1.8	.30 -.70	.25-.45	.06-.09
Business Jets	0.8-1.6	.30-.60	.25-.35	.06-.09
Jet Transports	1.4-1.8	.30-.80	.25-.40	.08-.10
Military Fighter/Attack	1.2-1.6	.25-.40	.20-.35	.03-.09

Fig. 6-18 Summary of Vertical Tail Geometric Characteristics

Figure 6: Fig. 6-16 and 6-17 from Schaufele for Tail AR and Taper Ratio λ

Instead of approximate fuel tanks as rectangles, the fuel tanks for the aircrafts are sized inside Solidworks, the shape is a smaller scaled version airfoil shape of the wing so that it can fully take advantage of the available space and affect CG location as small as possible. In fact, in aircraft stability, fuel tank is a component that changes weight the most, therefore, to ensure stability, fuel tank CG needs to be as close to quarter chord MAC as possible.

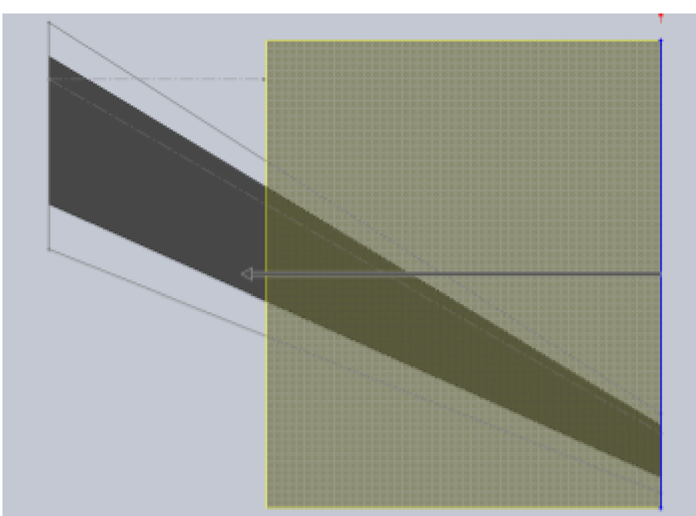


Figure 7: Sizing Fuel Tank

Front and rear wing spar locations are sized as recommended in Schaufele to be 15% to 75% of the chord. This is extruded all the way from root chord to tip chord. After that, the fuse tank is iteratively cut back from tip airfoil side until the desired fuel tank volume is reached

3.2 Fuselage and Exterior Configuration

Fuselage nose and tail was traced from the B737 aircraft drawing and scaled up to the required dimension of the diameter and length for the aircrafts. For the fuselage, the first cut is taken from the MATLAB code for a maximum fuselage length. After doing the interior layout in Section 3.4, a second cut is made for the minimum fuselage length. The fuselage length is then iterated in Center of Gravity (CG) sizing, increasing from minimum fuselage length to maximum fuselage length to make sure stability is satisfied while keeping the length as short as possible to avoid unnecessary weight and material cost.

Nacelles were sized to accommodate the scaled version of the JT9D engine. Sizing procedure follows Schaufele Figure 8-15. The size and shape of the nacelles are dictated by engine dimensions and performance requirements such as Bypass Ratio (BPR) and Sea Level Static Rated Thrust (SLSRT).

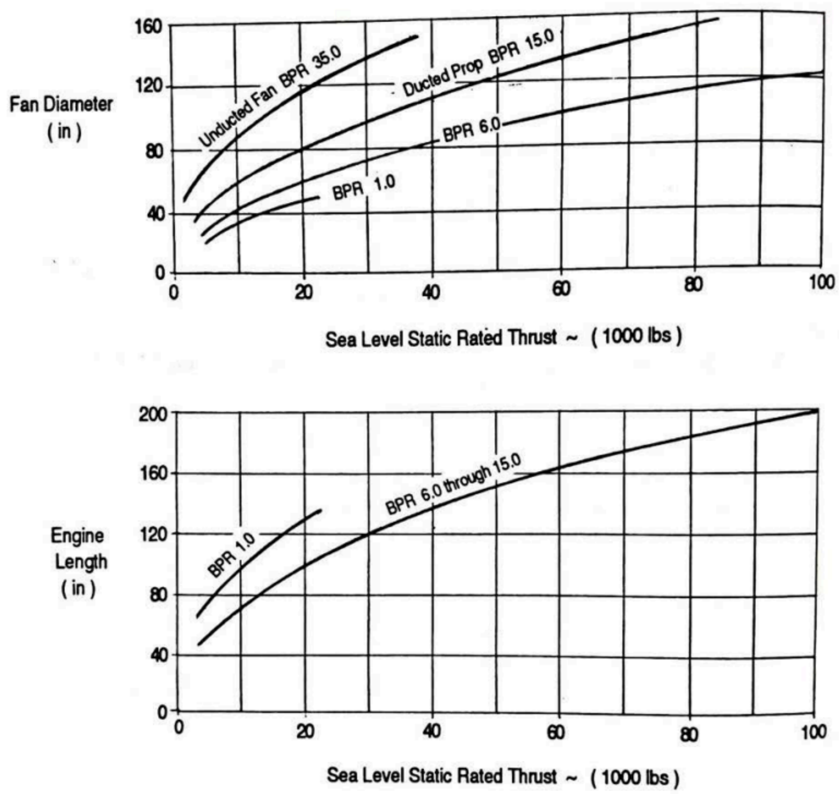


Figure 8: Fig. 8-15 from Schaufele for Nacelle Sizing

Landing Gear Sizing has two parts: one is tire selection and one is angle check. For tire selection, the main gear has to be able to take 100% of the TOGW while the nose gear is 15%

TOGW. With this requirement, in Course Manual Page 87, Figure 4.11, main gear is selected to have 8 tires, 4 tires each side, with rated load of 35,500 lb and dimension 44x16 inch while nose gear is selected to be 2 tires, 25,000 lb, and dimension 40x14 inch.

Type VII - Extra High Pressure Tires Main Wheels

Tire Size	Ply Rating	Max Width inches	Max Diam. inches	Loaded Radius inches	Tire and tube wt. lbs.	Commercial		Military	
						Press lbs/sq.in.	Rated Load lbs	Press lbs/sq.in.	Rated Load lbs.
24 x 7.25	10	7.3	24.0	10.3	29.7	120	6,600		
29 x 7.7	12-16	7.6	28.0	12.2	36-44	160	9,800	220	13,800
34 x 11	18	11.0	33.0	13.9	84.1	125	15,500		
36 x 11	24	11.1	35.0	15.0	86.2			220	25,600
40 x 14	22	13.5	39.2	11.8	112	145	25,000		
44 x 13	26	13.4	43.2	18.4	141.5			200	35,000
44 x 16	26	15.6	43.1	18.0	151.6	165	35,500		
56 x 16	24	16.0	55.8	24.1	258.7			178	45,000
56 x 16	32	16.1	55.8	24.1	296.3			240	60,000
56 x 16	36	16.1	55.8	24.1	297.0			280	71,000

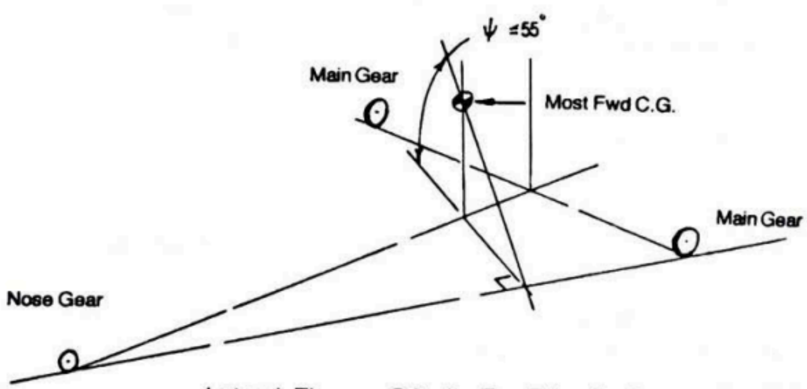
AERODYNAMIC DESIGN

Fig. 4:11. Tire Ratings. Ref. U.S. Rubber Co.

4:2

Figure 9: Fig. 5.22 from Course Manual for Landing Gear Tire Selection

Landing gear has to satisfy aft CG angle at least 20°, tip back angle lengthwise minimum 14°, tip back angle spanwise minimum 5°, and tipover criteria needs Ψ minimum 55°.



Lateral Tipover Criteria For Tricycle Gears

Fig. 7-2 Tipover Criteria for Landing Gears

Figure 10: Figure 7-2 from Schaufele for Landing Gear Sizing

Cargo Containers are decided based on the Interior Layout in Section 3.4. The cargo cannot be too big because there's no space for passengers. On the other hand, cargo cannot be too small because its length would need to exceed fuselage length to satisfy payload and also it requires extra materials to hold the aircraft structure integrity.

3.3 C.G Design

This follows Center of Gravity (CG) sizing procedure to make sure the aircraft CG location is always around MAC quarter chord for a tolerance of 10%. There are four extreme conditions the aircrafts can be in: design, empty, ferry, and landing. In design, all cargo, fuel and passengers are taken into calculation. In empty, none of them are considered. In ferry, only fuel is considered. And finally in landing, only cargo and passengers are considered. If all these extreme four conditions are satisfied, then all the combinations in between are also satisfied.

Component	Design			Empty		
	Weight	Length	Moment	Weight	Length	Moment
Wing	2.26E+04	1.84E+02	4.15E+06	2.26E+04	1.84E+02	4.15E+06
Fuselage	2.56E+03	2.66E+02	6.80E+05	2.56E+03	2.66E+02	6.80E+05
Landing Gear	7.67E+03	1.84E+02	1.41E+06	7.67E+03	1.84E+02	1.41E+06
Nose Tires	2.24E+02	1.44E+02	3.22E+04	2.24E+02	1.44E+02	3.22E+04
Main Tires	1.21E+03	1.89E+02	2.29E+05	1.21E+03	1.89E+02	2.29E+05
Nacel + Pylon	4.84E+03	1.72E+02	8.33E+05	4.84E+03	1.72E+02	8.33E+05
Tail	4.44E+03	2.56E+02	1.13E+06	4.44E+03	2.56E+02	1.13E+06
PP	2.44E+04	1.72E+02	4.19E+06	2.44E+04	1.72E+02	4.19E+06
Fixed Equipment	3.78E+04	1.84E+02	6.95E+06	3.78E+04	1.84E+02	6.95E+06
Fuel	7.21E+04	1.81E+02	1.30E+07	0.00E+00	1.81E+02	0.00E+00
PAX	4.52E+04	1.84E+02	8.30E+06	0.00E+00	1.84E+02	0.00E+00
Cargo	8.00E+03	1.84E+02	1.47E+06	0.00E+00	1.84E+02	0.00E+00
Sum	2.31E+05		4.24E+07	1.06E+05		1.96E+07

Ferry			Landing		
Weight	Length	Moment	Weight	Length	Moment
2.26E+04	1.84E+02	4.15E+06	2.26E+04	1.84E+02	4.15E+06
2.56E+03	2.66E+02	6.80E+05	2.56E+03	2.66E+02	6.80E+05
7.67E+03	1.84E+02	1.41E+06	7.67E+03	1.84E+02	1.41E+06
2.24E+02	1.44E+02	3.22E+04	2.24E+02	1.44E+02	3.22E+04
1.21E+03	1.89E+02	2.29E+05	1.21E+03	1.89E+02	2.29E+05
4.84E+03	1.72E+02	8.33E+05	4.84E+03	1.72E+02	8.33E+05
4.44E+03	2.56E+02	1.13E+06	4.44E+03	2.56E+02	1.13E+06
2.44E+04	1.72E+02	4.19E+06	2.44E+04	1.72E+02	4.19E+06
3.78E+04	1.84E+02	6.95E+06	3.78E+04	1.84E+02	6.95E+06
7.21E+04	1.81E+02	1.30E+07	0.00E+00	1.81E+02	0.00E+00
0.00E+00	1.84E+02	0.00E+00	4.52E+04	1.84E+02	8.30E+06
0.00E+00	1.84E+02	0.00E+00	8.00E+03	1.84E+02	1.47E+06
1.78E+05		3.27E+07	1.59E+05		2.94E+07

	CG	Delta CG	Delta CG
Design	1.84E+02	0.1364546776	0.76%
Empty	1.86E+02	1.722203485	9.63%
Ferry	1.84E+02	0.1772362095	0.99%
Landing	1.85E+02	1.145976928	6.41%

3.4 Interior Configuration

Because the range specification is at 3,500 nautical miles, the aircrafts are considered as Medium Range. From the Course Manual page 92, Table 2, all the necessary variables can be obtained to design the interior layout of the aircrafts.

First part of the interior configuration of the aircrafts is the circular cross section at middle of the fuselage.

Insert cross section

The cargo is in the bottom while passengers are on top.

After this is done, now the second part of interior configuration is the seating layout where the aircraft is cut horizontally in side view at the floor in the first part.

3.5 Selected Aircraft Configuration

TBlahblahblah

4. Configuration Drawings

5. Conclusion

Blah blah blah

6. Work Cited

[1] Performance predictor - Aerospace America.

[2] MAE 159 Appendix Hand Cal.pdf

[3] AR_vs_DOC.m

[4] Weight_takeoff_vs_DOC.m

[5] AR_vs_Weight_takeoff.m

[6] Course_Manual.pdf

[7] Psuedo_Code_2.m

[8] Sample_Calculation.m

[9] Schaufele.pdf