Sizing 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 84º 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

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1. Introduction

In this study, a commercial transport aircraft is designed and optimized for economic performance. The designed aircraft has to satisfy both safety requirements and the operational specifications such as range, speed, cargo weight, etc. After meeting all the requirements, the aircraft is then optimized for the best economical performance. Specifically, this study aims to minimize the aircraft's Direct Operating Cost (DOC). In order to achieve the minimum DOC, wing aspect ratio (AR) and swept angle (Λ) are varied. Furthermore, advanced technology is applied and compared with the existing technology to get better DOC performance.

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 commercial transport aircraft is required to meet. These design parameters define the aircraft's operational capabilities, including passenger and cargo capacity, range, takeoff, landing performance, and aerodynamic constraints. These specifications serve as the foundation for the design analysis, guiding the selection of trial configurations and the evaluation of advanced technologies to improve performance and reduce direct operating costs.

Mode	Configuration	Velocity	Minimum Gradient
1st Takeoff Segment	Gear Extended Flaps in Takeoff Engine out	> 1.2 V_stall	0.00%
2nd Takeoff Segment	Gear Retracted Flaps in Takeoff Engine out	> 1.2 V_stall	2.40%
3rd Takeoff Segment	Gear Retracted Flaps Retracted Engine out	> 1.2 V_stall	1.20%
Approach	Gear Retracted Flaps in Takeoff Engine out	> 1.3 V_stall	2.10%
Landing	Gear Extended Flaps in Landing All Engine	> 1.3 V_stall	3.20%

Table 2: Safety Requirements for 2-Engines Aircraft

Besides the explicit design specifications in Table 1, the aircraft also has to meet the safety requirements in Table 2. The Mode column describes what flighting phase the aircraft is in. The first three rows belong to the climb gradient section. In this section, aircraft velocity has to be greater than 1.2 the stall velocity and minimum gradient ensure that there's enough clearance for the aircraft to take off without infrastructure interference. Similarly, in approach and landing phase, the aircraft has to travel at greater than 1.3 the stall velocity and the minimum gradients ensure departure clearance and also space for correcting if there's engine failure.

1.2 Goals of the study

The final objective of this study is to find the design that satisfies all the requirements and has the lowest DOC. This is achieved by iterating aircraft design parameters and applying advanced technology. Therefore, three smaller objectives can be laid out as:

1. Optimizing Aircraft Design Parameter: Find the wing aspect ratio (AR) and swept angle (Λ) combination that gives the lowest DOC.

2. Comparing Conventional and Advanced Technology Designs: Applying advanced technology to the aircraft design and comparing it with the conventional technology.
3. Selecting an Optimal Final Design: A final design will be selected that gives the best economic performance while meeting the design requirements.

2. Design Analysis

The design process involves multiple phases including the initialization of the code [1], accuracy validation via hand calculations [2], adaptation to current design [3], and iterations for optimization [4] [5] [6]. This report serves as the next step in this process, analyzing the data gathered from the optimization process.

2.1 Basis for selection of trial designs and parameter variations

Rating	Engine Jet Thrust [Lb]	
	JT8D	JT9D
Take-Off Rating	14,500	47,000
Maximum Continuous Rating	12,600	38,500
Maximum Climb Rating	12,600	38,500
Maximum Cruise Rating	11,400	35,500

Table 3: Engine Thrust for JT8D and JT9D engine.

Between JT8D and JT9D engine, the JT9D engine is selected because its maximum thrust is more than double the JT8D engine (Table 3) which is more suitable for mid range flight at 3,500 nautical miles. In addition, the engine used for this aircraft is not the exact JT9D engine but a scaled version of the JT9D engine so that it most fits the design.

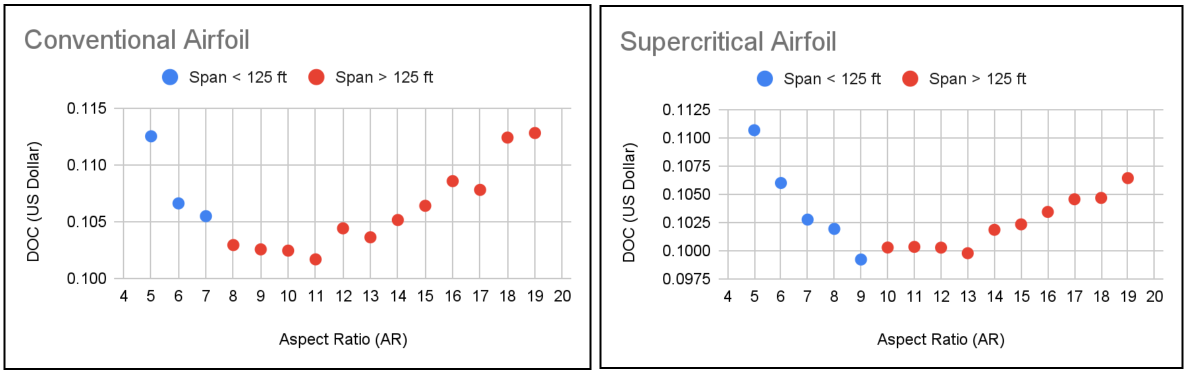

Figure 1: Airfoil for Aircraft with $\Lambda = 25°$ and Existing Technology.

For airfoil, the supercritical airfoil is selected instead of the conventional airfoil because the conventional airfoil fails the gate requirements (wingspan is less than 125 ft) at the converged minimum DOC. Figure 1 shows that for conventional airfoil, the DOC converges at AR = 11. However, the wingspan starts to fail at AR = 8 already. On the other hand, for supercritical airfoil, the DOC converges at AR = 9 which is also where the span requirement starts to fail. Note that this is specifically for the current specifications, if the specifications are different, this can become another parameter needed to take into consideration.

Aspect ratio AR and swept angle Λ are not evaluated as individual parameters like engine and airfoil type but as different combinations. Moreover, at this stage, advanced technology is also taken into consideration. Therefore, in this section, three independent variables are aspect ratio AR, swept angle Λ, and Advanced Technology; and the dependent variable is DOC. The following analysis will aim to find the absolute minimum DOC in this 4 dimensional space.

2.2 DOC versus Performance

In the three independent variables, the easiest variable to decouple is Advanced Technology because there are only three choices for this variable: Existing Technology, Advanced Technology with Composite Structure, and Advanced Technology with Aluminum/Lithium Structure.

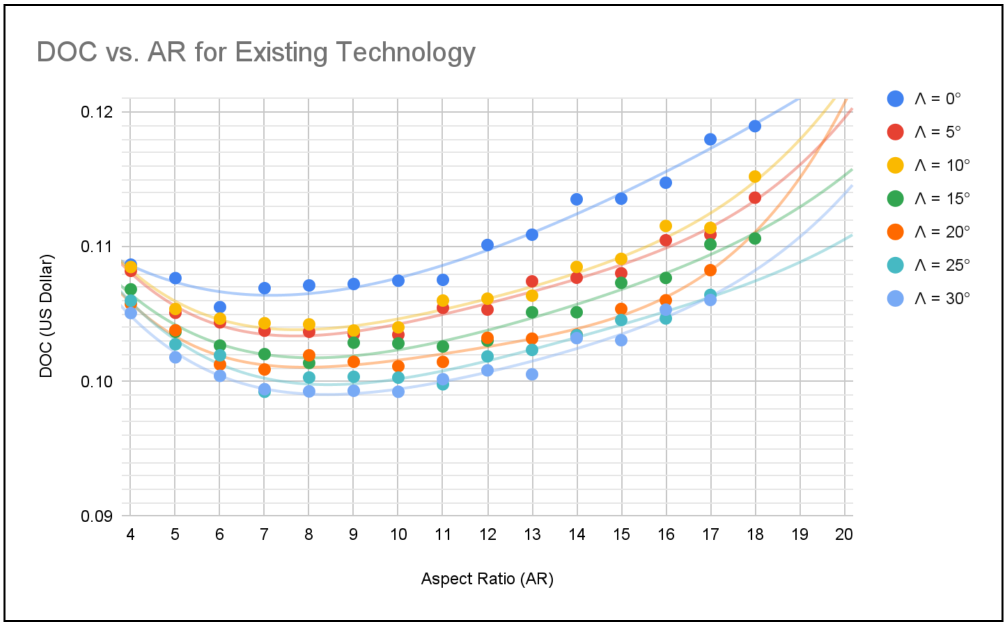

Figure 2: DOC vs. AR for Existing Technology Aircraft

One thing worth noting is that the span requirement fails for AR > 8. Therefore, even though AR = 8, 9, 10 give similar DOC, only AR = 8 is chosen. For swept angles, the curve fit for Λ = 30° gives an obvious advantage compared to other swept angles. Further swept angles were experimented but they failed the safety requirements listed in section 1.1.

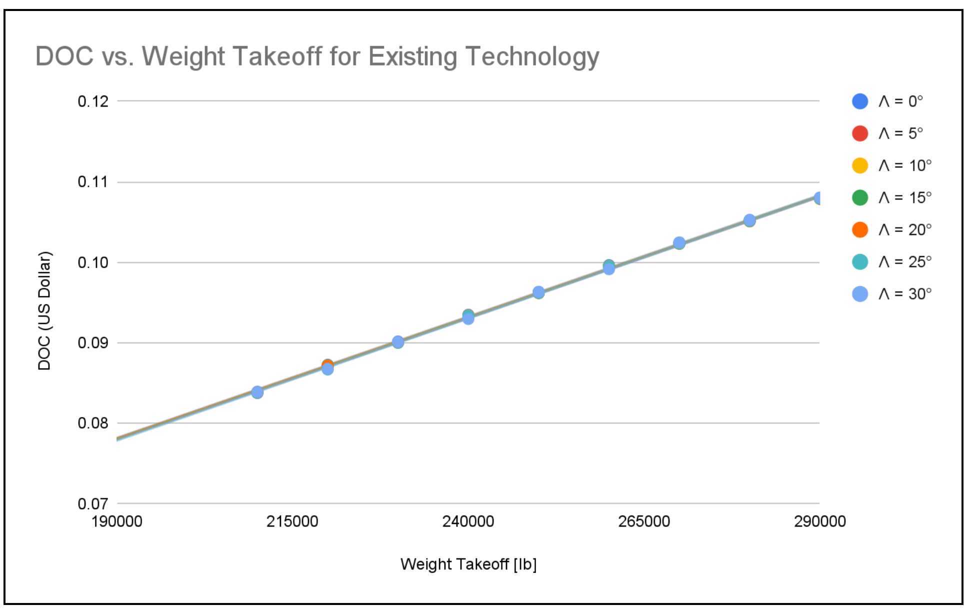

Figure 3: DOC vs. Takeoff Weight for Existing Technology Aircraft

The Takeoff Weight and DOC have a linear relationship. As Takeoff Weight increases, DOC increases. As Takeoff Weight decreases, DOC decreases. Therefore, if Takeoff Weight is minimized, DOC is also minimized. To confirm this, the plot of Takeoff Weight and AR is generated in Figure 4.

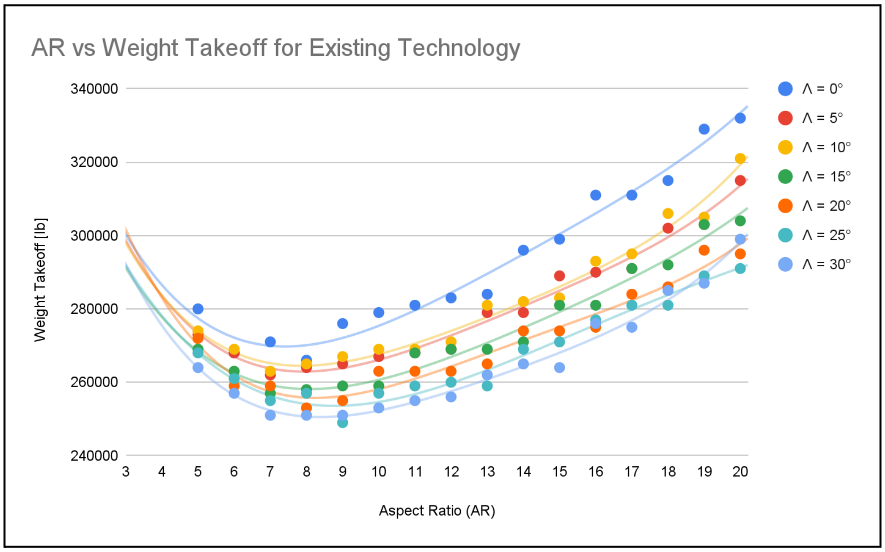

Figure 4: AR vs Takeoff Weight for Existing Technology Aircraft

Figure 4 is similar to Figure 2: DOC vs. AR because DOC and Takeoff Weight are similar and can be simultaneously used for optimization. This leads to the discussion of Advanced Technology because Advanced Technology can significantly reduce Takeoff Weight of the aircraft.

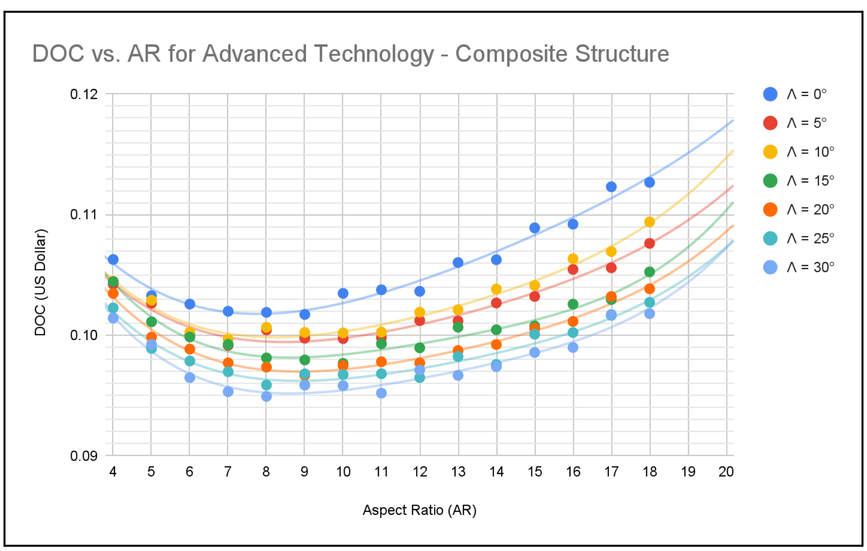

Figure 5: DOC vs. AR for Advanced Technology - Composite Structure

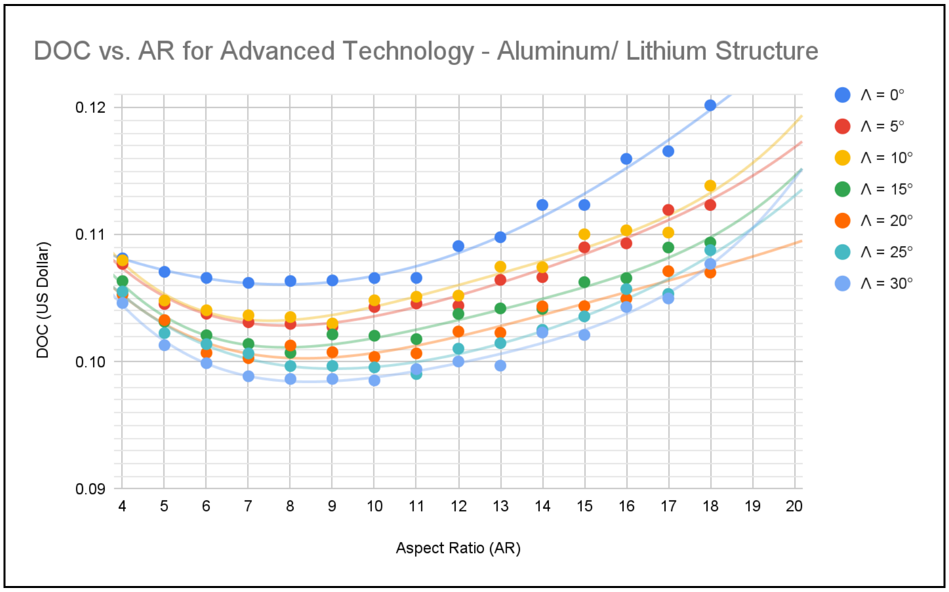

Figure 6: DOC vs. AR for Advanced Technology - Aluminum/ Lithium Structure

2.3 Basis for selection of the final design(s)

The core of the selection for the final design will be the lowest DOC points in Figure 2, 5, and 6. All three figures show a clear indication of swept angle Λ = 30°. Aspect ratio AR is limited at AR = 8 due to maximum span requirements but at the same time, it also converges to the minimum DOC. The minimum DOC values at Λ = 30°and AR = 8 are recorded in Table 4.

Technology	**DOC (US Dollar)**
Existing Technology Aircraft	0.1004189516
Advanced Technology - Composite Structure	0.09648978684
Advanced Technology - Aluminum/ Lithium Structure	0.09989424741

Table 4: DOC comparison between advanced technology at optimal design Λ = 30°and AR = 8

From Table 4, the lowest DOC is Advanced Technology - Composite Structure. Therefore, the final design will have swept angle Λ = 30°, aspect ratio AR = 8, and use Advanced Technology - Composite Structure.

Another aspect

2.4 Specifications of the final design(s)

Tables

Payload graphs

3. Conclusions

Blah blah blah

4. Acknowledgments

I want to thank T.A. Seraphin Yeung and Prof. Robert Liebeck for teaching and lecturing about the necessary theory in order to grasp the purpose and scope of this study.

5. References

[1]

[2]

[3]

[4]

6. Appendices:

Look for Appendix Assignments for MATLAB code and Hand Calculations