AIRCRAFT DESIGN

SUBSONIC JET TRANSPORT

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Abstract

The purpose of this report is to design the results of a given specification and to optimized parameter variation that leads to data collection through Matlab and Excel. The sizing of the aircrafts and the drawing of the aircrafts are done through Solidworks. The requirements such as center of gravity, tail sizing, fuel capacity, and wing layouts are made and located to locations that meets the criteria. The detailed drawing specification allows the analysis through calculations to verify the criteria's that are required. The safety and comfort level of passengers are one of the key factor for the design layout of the two aircrafts.

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I. Summary of the Airplane Design Study

Design Specification:		
Number of Passengers	150	220
Weight of Cargo	3000 lbs	3000 lbs
Range Requirement	3500 nautical-miles	3500 nautical-miles
FAR-Takeoff Field Length	7500 feet	7500 feet
Landing Approach Speed	135 knots	135 knots
Cruise Mach Number	0.8	0.8
Initial Cruise Altitude	35,000 feet	35,000 feet

Table 1: Design Parameter Specification

Design Specification and Problem

The purpose of this study is to two subsonic aircrafts, one to transport 150 passengers and the other to transport 220 passengers while fulfill requirement of 3500 nautical-miles. This examines how and why certain parameters affect each other in relation to the final direct operating costs, and to find the most cost efficient design. The specified requirements give numerous methodology that enables countless design parameters, in order to obtain optimal direct operating costs. The preliminary design of the two subsonic aircrafts sizing requirements are optimized for the direct operating costs. With the collected data, these data are optimized through numerical and graphical analysis that selects parameters to output favorable economic value. These analyses are the basis of the rationale for the selection of the optimized aircraft parameters and the preliminary design of the two aircrafts.

The Matlab code gives capability to vary parameters with relative values of direct operating cost. The ranges of aspect ratios and the sweepback angles are varied with number of engines and produce eight sets of data for two aircrafts, type of airfoil, number of aisles, and number of engines.

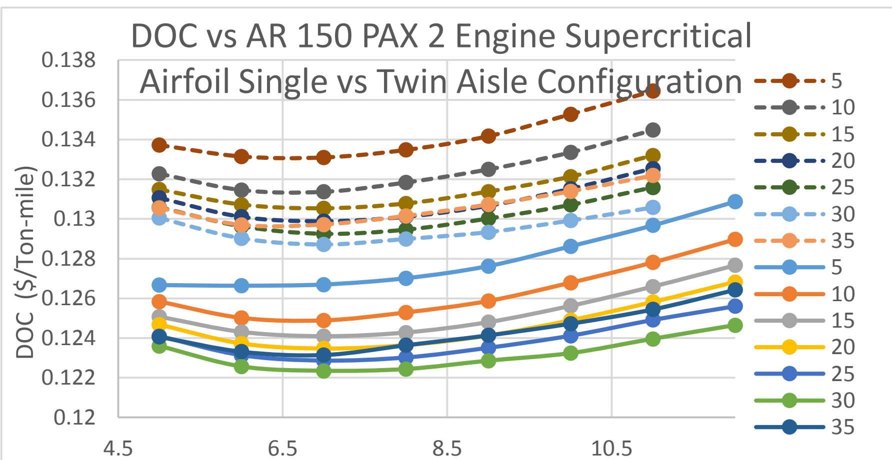


Figure1: Plot of DOC vs AR for Single and Twin Aisle Configuration

These data, concurs that at sweep angles 25-30 degrees and at aspect ratio of 6-8 gives the optimal direct operating costs. Thus, with sweepback angle of 30 and aspect ratio of 7 was selected for 220 PAX design. For the other aircraft for 150 PAX design favored sweepback angle of 25 degrees and aspect ratio of 7. These two parameters selected are varied with other parameters to calculate the optimal design specs.

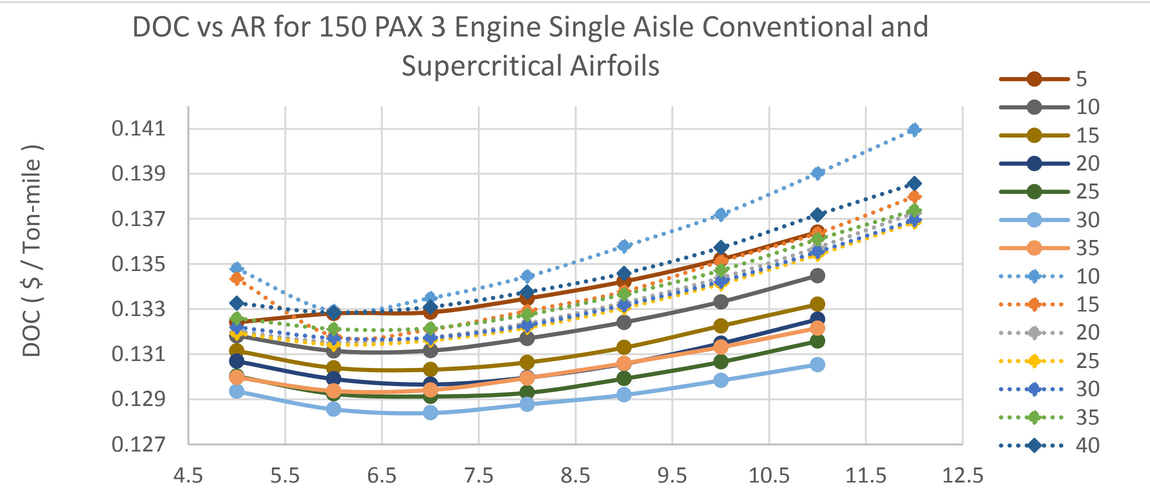


Figure2: DOC vs AR 3 Engine 150 PAX Single Aisle Configuration for both Airfoils (Solid Line: Supercritical Airfoil; Dotted Line: Conventional Airfoil)

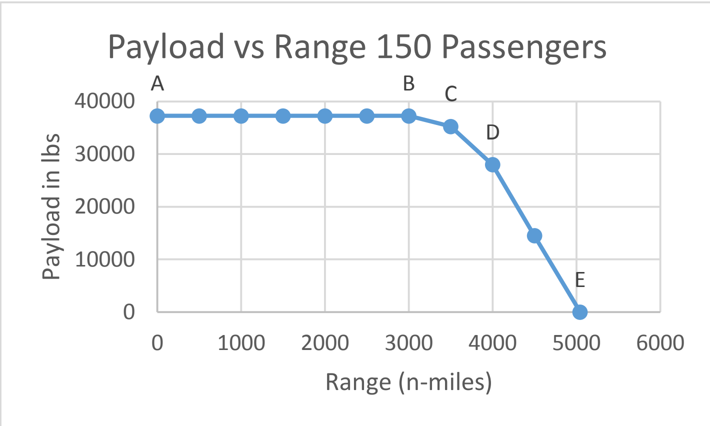
The 220 passengers with single aisle twin engine configuration generates optimal direct operating costs, however, the difference in the direct operating costs between aisle configuration is by 0.0068 ($/Ton-mile). The twin aisle configuration for 220 passengers are to be chosen even with higher direct operating costs because of the growth sensitivity and comfort level to the passengers. The advance technology that are used for airframe are composites or Al-Li structures. As composites give significant reduce in weight, it is not commonly used for airline flights which operates numerous short range flights per day. The management of composite structures will increase DOC whereas the usage of the composite structures for day-to-day flight will decrease DOC through weight reduction. However, the risks that arise from composite structure are producing, repairing and managing the airframe have the highest risk factors not only to DOC, but also in chance of accidents. It is because even composites have weight reduction, processing the carbon composites are arduous and will produce increase in labor cost. Composite structures cannot have air bubbles within the layers and detection of these bubbles through ultrasonic is arduous. Also, reparation process of composites are not simple, new methods and more skilled inspection and inspectors needs to be trained. Contrarily, Al-Li alloy structures yield weight reduction not as much as to composites, it has several advantages over composites. During operation, the aluminum-lithium alloy structures can withstand stresses done multiple daily flights. As well as damage control of this airframe has similarity to traditional aluminum airframes where the damaged surfaced can be surface sanded for cracks and use scab patches. Carbon composites contain higher strength with lower weight, however, in an impact such as a crash, aluminum-lithium alloy absorbs energy as it is crushed, and the carbon composites will shatter. In conclusion, even carbon composites composing strength of the material and the weight reduction, aluminum-lithium alloys offsets carbon composites by robust factors in production, maintenance, reparation process and the impact tests.

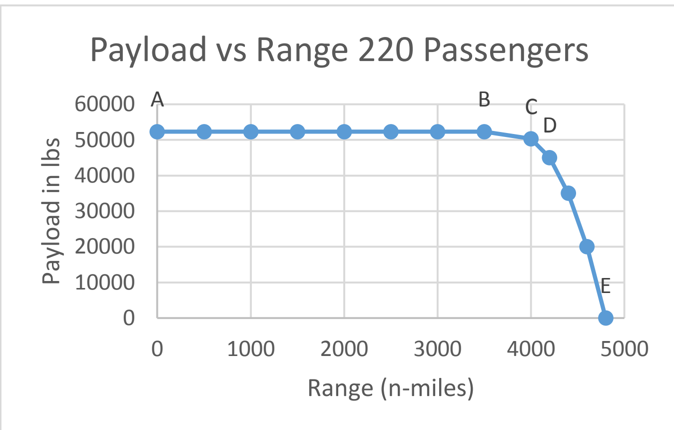
The usage of aluminum-lithium alloy in the airframe allowed reduction in direct operating cost and weight. Carbon composite was not used even though composites yielded more weight reduction, due to complex manufacturing, maintenance and repairs made aluminum-lithium alloy appropriate material to be selected. As for 150 passenger aircraft are simply twin engine located on wings, single aisle with Al-Li alloy which yielded the optimal direct operating costs. Two engines are mounted on the wing to minimize the cost for both 150 and 220 passenger aircrafts. The number of crew and stewardess were kept constant to have same comparison factors for varying parameters.

Specifications of the Preliminary Designs

PRELIMINARY DESIGN SPECIFICATIONS		
	Plane #1	Plane #2
Number of Passengers	150	220
WING PARAMETERS		
Type of Airfoil	Supercritical	Supercritical
Sweepback Angle	25	30
Aspect Ratio	7	7
Span (ft)	101.12	120.64
Planform Area (ft^2)	1421.258	2079.04
Advanced Technology	Used	Used
FUSELAGE		
Length (ft)	127.20	171.07
Diameter (ft)	13.08	14.66
ENGINE PARAMETERS		
Type of Engine	P&W - JT9D	P&W - JT9D
Advanced Technology	No	No
Number of Engines	2	2
Location of Engines	Wing	Wing
INTERIOR CONFIGURATION		
Number of Crew	2	2
Number of Stewardess	3	3
Number of Aisles	1	2
Number of Abreasts	6	7
WEIGHT		
Structural Material	Al-Li Alloy	Al-Li Alloy
Take-Off Weight (lbs)	194001.10	276096.28
Fuel Weight (lbs)	64784.30	83258.54
Payload Weight (lbs)	35250	50300
OPERATION COSTS ($ / TON-MILE)		
Flight Crew	0.015323	0.011966
Fuel and Oil	0.051321	0.049864
Insurance	0.003063	0.002808
Maintenance	0.024357	0.021226
Depreciation	0.024182	0.022093
Direct Operating Costs: D.O.C.	0.118245579	0.10795736

Point by point inspection of the 150 and 220 PAX, it is concluded that both aircraft design would be using two JT9D engines located on the supercritical wings. Wing span of both designs are critical due to limits of hangar, limitations accustomed by FAR25 regulation, and the spans hold about 101 feet and 121 feet for 150 and 220 passengers, respectively. Length of the fuselage heavily depends on interior configuration and the lengths generated are 127.20 feet and 171.07 feet, respectively. It is rather costly to travel on smaller 150 PAX design than 220 PAX design because of 220 PAX design yields lower costs even with twin aisle configuration. The effect of utilizing the wing parameters and geometry from 220 passenger design to the 150 passengers. The sweep back angle is selected to be at 25 degrees for 150 passenger design configuration.





The payload range chart shows the distance that the specific aircraft can travel with payload and the trade-off between the payload and the fuel to increase range. Point A-B has full payload with 2000lbs extra, point C is the design payload and range, point D is the trade-off between fuel and payload, finally point E is full fuel with no payload.

II. Description of the Configuration

Two aircrafts have been designed and 3D modeled based on the previous analysis. First aircraft with 150 passengers and second aircraft with 220 passengers are met with the requirements such as fuel capacity, center of gravity which leads to tail sizing, emergency exits, lavatories, galleys, seat pitch, and aisle width diameter. The dihedral angle of the main wing and the horizontal tail is to have lateral stability. Both aircrafts used Whitcomb Integral Supercritical Airfoil as the main wing airfoils and TR-51 and NACA 0009 for horizontal and vertical tails,

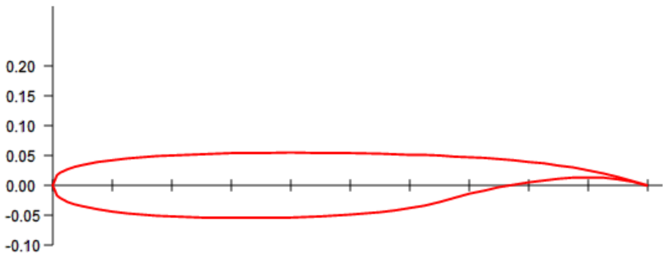


Figure3: Whitcomb Integral Supercritical Airfoil

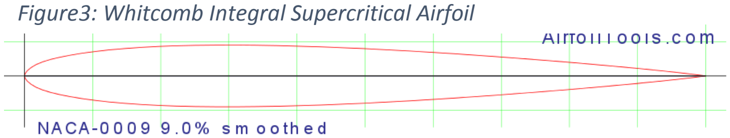


Figure5: NACA-0009 Airfoil

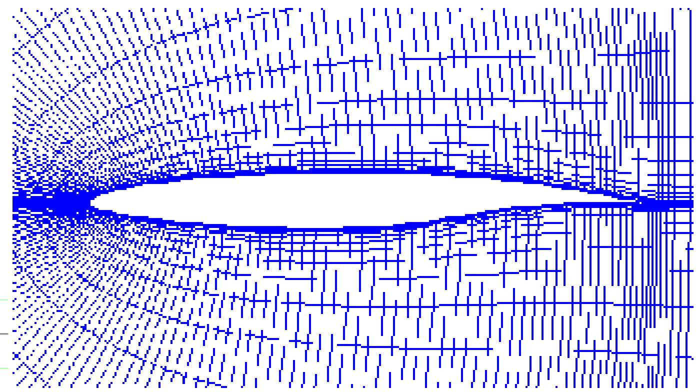


Figure4: TR-51 Airfoil

respectively. First aircraft that are capable of carrying 150 passengers have dihedral angle of 7 degrees for both main wing and horizontal tail. Also, the second aircraft has 7 degrees dihedral angle. The horizontal tails have different characteristics between both aircrafts. The first aircraft has aspect ratio of 5 for horizontal tail and 1.5 for vertical tail, whereas the second aircraft had the aspect ratio of 3.5. By having higher aspect ratio, the sweep angle was also 25 degrees for the 150 passenger aircraft, however, the area of the horizontal tail was much higher than that of 220 passenger aircraft. This can be an error caused in the calculations for tail sizing. The taper ratio was same, however, the both aircraft used TR-51 airfoils. As for the vertical tail, the first aircraft yielded aspect ratio of 1.5 and 1.2 for the second aircraft and used NACA-0009 airfoil for the symmetric characteristic of this airfoil. The vertical tail on the first aircraft generated higher surface area, but not as much as compared to horizontal tail. Every tail surfaces are swept back equally as their main wing. Also, the volume coefficient for both aircrafts are held at 1.10 and 0.08, horizontal and vertical tail respectively. Both aircrafts also has same amount of doors and emergency exit doors which are type A, 2 x B and I doors. The type B doors are mainly used for entry and exits, and type A and I doors can be used as emergency exits. The number of lavatories and galleys were calculated to the function of how many passengers it holds to satisfy the comfort level of the passengers and were located front and aft portion of the plane. To meet the requirement of cargo and extra baggage of passengers, LD-W type containers are used for the first plane and the LD-2/LD-3A type are used for the second plane. LD-2/LD-3A cargo containers are bigger and holds more volume for the second plane and it was able to fit under the cabin floor compartments. LD-W containers holds about 96.6 cubic feet and LD-2/LD-3A cargo containers holds 266.55 cubic feet of volume. Total of 8 LD-W containers are used for first plane and 5 LD-2/LD-3A containers are used for second plane. The location of these containers are located front and aft portion of the wing so that it would not perpetuate the center of gravity. The center of gravity is calculated for four cases: full fuel and full payload, full fuel and no payload, no fuel and full payload, no fuel and no payload. The center of gravity was calculated and determined to be at the position where these four conditions were within the range of 10%. The location of center of gravity is critical due to tip-back and tip-over condition requirements that need to be met. These requirements lead to tail clearance and landing gear sizing and its locations. The landing gears and tires are chosen with the take-off weight. Determined by the take-off weight, the first plane with 150 passengers, the main gear and nose gear dimensions are given as: 46" x 14" (diameter x width), and 26" x 7.7". Main gear has four wheels per strut and the nose gear have two wheels. The second plane with 220 passengers needed larger tires due to the take-off weight and its dimensions are: 46" x 16" main gear and 40" x 14" for the nose gear. These landing gears have been accounted for the compression and static loading and with the models shown, the lengths of the landing gears will fit into the fuselage. This chart shows the fuel capacity of each aircraft.

Fuel Volume	150 PAX	220 PAX
Cubic Feet	1032.855	1566.24
US Gallons	7726.29	11716.3

The interior configuration of the both of the aircraft is different, while first plane for 150 passengers have more seat in the first class with 42" and 32" for economy, the second plane for 220 passengers have seat pitch of 40" first class and 34" for economy. The seat pitch for economy is larger for 220 passenger aircraft because it uses 2-3-2 seats abreasts twin aisle configuration. The number of lavatories, galleys and coat room are shown in the figure below.

Interior Configuration	150 PAX	220 PAX
First Class Seats	12	20
Economy	138	200
First Class Seat Pitch (inches)	42	40
Economy Seat Pitch	32	34
First Class Seat Abreast	4	4
Economy Seat Abreast	6	7
Galleys	5	4
Lavatories	5	6
Rows	25	36

The detailed location of these interior items will be shown in the next pages with the interior layout. The decision to locate the nacelle and the engine to be placed are determined to be near the mean aerodynamic chord for both aircrafts, which uses two Pratt&Whitney Turbofan-JT9D engines. The location of the engine was chosen to at near the mean aerodynamic chord, almost at half the length of the wing. The next pages will give the summary and characteristics of the aircrafts. The center of gravity is required to be within 10% of mean aerodynamic chord. This chart provides the center of gravity for four cases that locates the main wing and satisfies the tip-back and tip-over angles. The chart values are within the 10% range of the mean aerodynamic chord

CG – 150 PAX	Location Front Fuselage
Full Payload Full Fuel	40.1782
Full Payload No Fuel	45.9319
No Payload Full Fuel	41.3902
No Payload No Fuel	50.0243

CG – 220 PAX	Location Front Fuselage
Full Payload Full Fuel	67.479
Full Payload No Fuel	65.3
No Payload Full Fuel	67.8
No Payload No Fuel	65.113

Future References

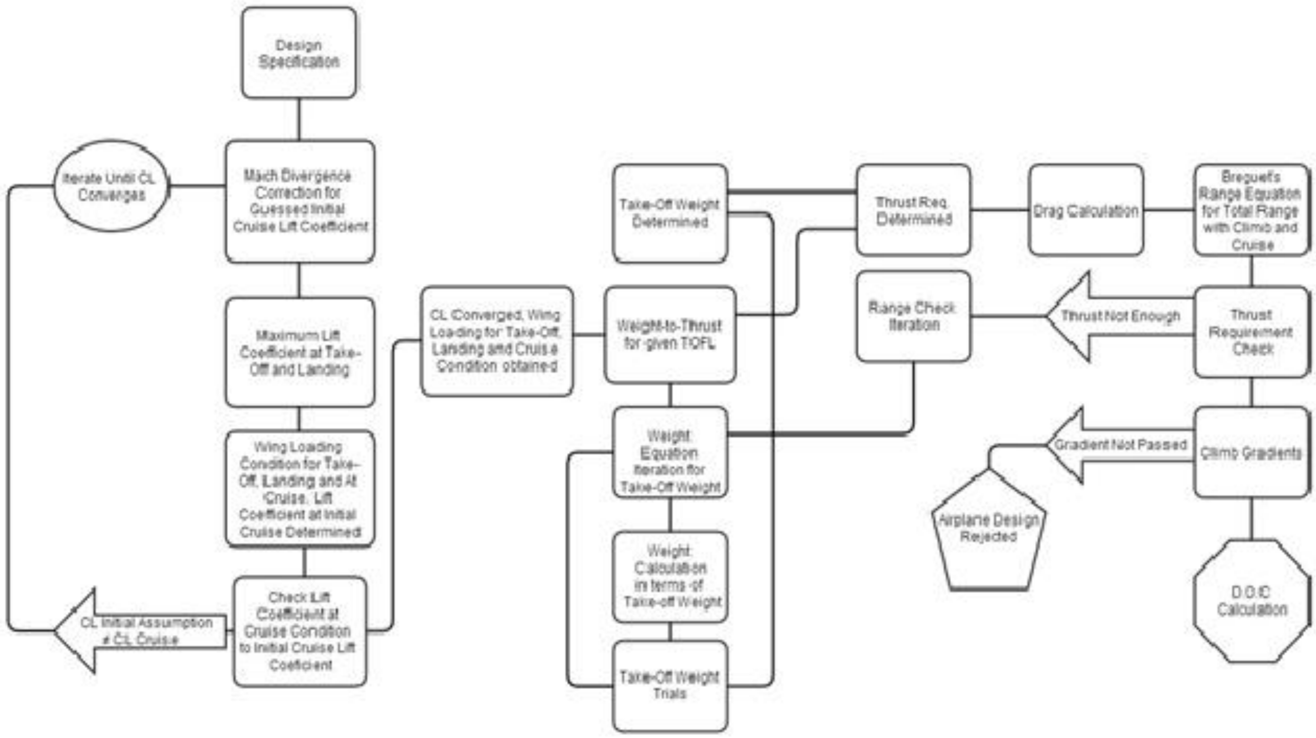
The design of the two aircrafts for future consideration, the CG has to be calculated carefully to satisfy the tail sizing conditions. It seems to have error in the tail sizing calculation because of the values of 150 passenger aircraft tail surfaces are higher than that of 220 passenger aircraft. The 3D modeling with Solidworks has been a challenge, however, the 3D modeling made calculations and drawings much easier with huge time consumption.

III. Configuration Drawings

IV. <u>Conclusion</u>

In summary, the design specifications for both of the aircrafts are based upon the data that were computed by Matlab and hand calculations and drawn by Solidworks. By comparing two aircrafts side by side, the tail sizing have errors that were unforeseen. The vertical tail for 220 passenger aircraft is too small and the surface area for horizontal tail for 150 passenger is too large. The interior configuration and other requirements are met such as tip-over and tip-back requirements also the tail clearance angle for rotation. The number of cargo containers, fuel capacity and the landing gear clearance requirements are satisfied with the shown layout. Hence, the design specifications for the aircraft configurations are content with surplus of minimum requirements.

V. <u>Matlab Flow Chart</u>



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