Aircraft Design Project

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1-Abstract & Theoretical Discussion

First thing to do after getting an offer for an aircraft,is to gather around some peer aircraft (an aircraft which is close to the wanted aircraft in the mission based on its Category, Size, Weights, Range and etc.) data and try to design based on their data,it is obvious that,as much as your peer aircrafts are more,your work would be better.

Then we need to choose a target aircraft (an aircraft which parameters are very close to our mission specification). then we'are ready to start designing.

The first step in designing an aircraft, is to estimate the weight of the aircraft during take-off. To weigh the take-off weight we first need to obtain a range of these weights according to data base then initial Take-off weight gain will be estimated. Our values need to be obtained for $W_{OE\ tent}\ and\ W_{E\ tent}$ and for this purpose we need to calculate the Mff. Then with considering the amount of W_E and $W_{T.O}$ form data base we can gain the values of $W_{T.O}$,W_E for mission aircraft, earned percentage of error must be below 0.5 percent, while the take-off weight of the aircraft is calculated.

At the end,we need to chart some graphs. these graphs are named 'sizing' and they are 8,first we introduce them:

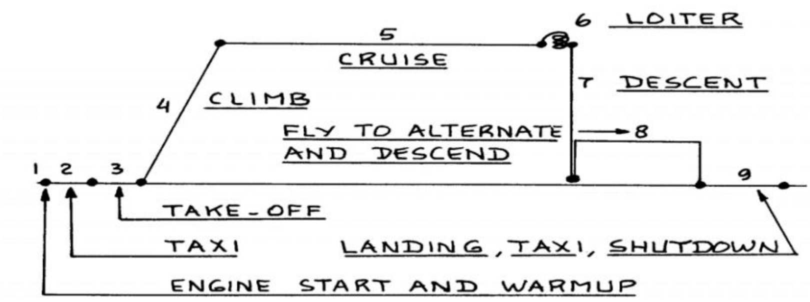
1. Stall Speed
2. Take-off Field Length
3. Landing Field Length
4. Climb Rate
5. Cruise Speed
6. Ceiling
7. Time to Climb
8. Maneuvering

The purpose of calculating these spoken Sizing's is to chart T/W vs W/S (Matching Diagram) and specify the design area.this design area is a part of above graphs which in it,designing is much more economic.
Sizing information about each of the following calculations method will be explained in detail. Finally, by drawing Matching Diagram and specify the design area, the point at which the maximum W/S and the lowest T/W is such that the lowest weight and cost will be reached.

In the next step we will show you our mission.

2-Mission Specifications

Mission Specifications for a Transport Jet	
Payload	400 Passengers at 175 lbs and 60 lbs of Baggage Each.
Crew	2 Pilots and 8 Flight Attendants at 175 lbs and 30 lbs of Baggage Each.
Range	6,500 nm, followed by 0.75 hour loiter, followed by a 300 nm flight to alternate.
Altitude	35,000 ft (for the design range).
Climb	Direct climb to 35,000 ft in 20 minutes. At max. WTO is desired.
Cruise Speed	M = 0.84 at 35,000 ft
Take-off and Landing	FAR 25 take-off field length 10,500 ft and 8000 ft landing field length at 100°F (Hot day) in Kerman Airport.
Power Plants	Two Turbofans
Pressurization	6,000 ft. cabin at 35,000 ft.
Certification Base	FAR 25



As we said before, we have to find a target aircraft.

3-Introducing the Target Airplane

According to the mission, from the data base collected, the closest aircraft in flight range, speed cruise and weights, is Boeing 777-300ER.

Boeing 777-300ER, first flew on 24 February 2003 and on 10 May 2004 aviation fleet was entered. With two pilots and capable of carrying 365 passengers in a three classes fly. The price of this model is between 250 to 279 million dollars.

In undercarriage discussion it has retractable tricycle with two main wheels and a retractable guide wheels on the nose.

327565 lbs fuel capacity and also has two engines (General Electric turbofans (GE90-115B)).

The aircraft is capable of flying at a distance of 7705 nm or 14,270 kilometers.

Compared to the 777-300 model has a stronger engine and the ability to carry more fuel in the wings.

Everything is set now and we need to start working!

4-First Step

Take a little glimpse at what we are about to do:

First using the mission we obtain W_{Crew} & W_{PL}.

$$\mathrm{W_{PL}} = 400 \times (175 + 60) = 94000\mathrm{lbs}$$

$$\mathrm{W_{Crew}} = 10 \times (175 + 30) = 2050\mathrm{lbs}$$

Then we need to come up with a guess for $W_{T.O}$ (using peer aircrafts data.).
After that with weight ratios in any phase of flight we are going to calculate Mff.
And, using Mff amount to calculate $W_{OE_{tent}}$ & $W_{E_{tent}}$.
Now with the use of peer aircrafts data we draw log $W_{T.O}$ vs log W_E in Excel linear regression plot and erasing data which are far above the regression line obtained. The values A and B are now determined.

$$\log W_{T.O} = A + B \log W_E$$

They should be close to book values Roskam said, then using W_E we obtain the maximum allowed take-off weight.

Now, the difference between $W_{E_{tent}}$ and W_E is obtained. By using computer software's and try error method (with changing the amount of $W_{T.O}$ we have guessed before.) we should make the difference come to zero. Having the final step repeat then we have a suitable amount of $W_{T.O}$.

Now we are going to use the above method:

4.1.1-Estimating Take-Off Weight

First, we need an initial guess for estimating take-off weight of the aircraft according to peer aircrafts data. W_{PL}, cruise speed and range of the peer aircrafts are specified.

Airplane model	W_{PL}	R	V_{CRUISE}	$W_{T.O}$
B777-200LR	69740	11000	0.84	766000
B777-200ER	131000	7730	0.84	656000
B777-300	147200	5950	0.84	660000
B777-300ER	87120	9470	0.84	775000
A350-1000	46050	8000	0.85	681000
B777-F	226000	9300	0.84	766800
B747-400M	137521	7214	0.84	875000
B747-400DOMESTIC	246000	1805	0.85	833000

Given the range defined in the mission and the payload weight, and from peer aircrafts data we can estimate the take-off weight.so we guessed:

$$W_{T.O_{Guess}} = 680000 lbs$$

4.1.2-Calculating Mission Fuel Fraction

$$M_{ff} = \frac{w_9}{w_8} \times \frac{w_8}{w_7} \times \frac{w_7}{w_6} \times \frac{w_6}{w_5} \times \frac{w_5}{w_4} \times \frac{w_4}{w_3} \times \frac{w_3}{w_2} \times \frac{w_2}{w_1} \times \frac{w_1}{w_{T.O}}$$

Some weight fraction given in Table 2.1 Roskam:

$\frac{W_1}{W_{T.O}}$	$\frac{W_2}{W_1}$	$\frac{W_3}{W_2}$	$\frac{W_4}{W_3}$	$\frac{W_7}{W_6}$	$\frac{W_9}{W_8}$
0.990	0.990	0.995	0.980	0.990	0.992

As a result, only weight ratio in phases, Cruise, Loiter and Fly to alternate needs to be calculated.

4.1.3-Calculating Cruise to Climb Weight

To calculate the weight ratio in the cruise phase, we use the following formula:

$$\mathrm{R_{Cr}} = \left(\frac{\mathrm{V}}{\mathrm{C_j}}\right)_{\mathrm{Cr}} \times \left(\frac{\mathrm{L}}{\mathrm{D}}\right)_{\mathrm{Cr}} \times \ln\left(\frac{\mathrm{W_4}}{\mathrm{W_5}}\right)$$

R is the range of aircraft, Cj represents the amount of fuel consumption at this point, and V shows the speed of cruise in Mach term that is defined in the mission, and V should be based on Knots.

To calculate the speed of Cruise in Knots:

$$\mathrm{V_{Cr}} = \frac{\mathrm{M}\sqrt{32.2\,\gamma \mathrm{RT}}}{1.6878} = 482.27 \text{ Knots}$$

And we have:

$$\gamma = 1.4$$
$$\mathrm{R} = 53.3 \ {}^{\mathrm{ft} * \mathrm{lbf}}/_{\mathrm{lbm}}$$
$$\mathrm{T} = 389.958 \ \mathrm{R}$$

And also we have to correct the height change, that’s why we divided the velocity to 1.6878.

In order to find the range of cruise, we have:

$$\mathrm{R_{Cr}} = \mathrm{R} - \mathrm{R_{Climb}}$$

To calculate the range of climb we need the speed of climb.

$$\mathrm{R_{Climb}} = \frac{20}{60} \times \mathrm{V_{Climb}}$$

Climb speed mode is given by the formula:

$$V_{Climb} = \frac{V_{Cr} + V_{T.O}}{2}$$

$V_{T.O}$ for target aircraft (B777-300ER) is 186.83 Knots.

Then:

$$V_{Climb} = \frac{186.83 + 482.27}{2} = 334.55 \text{ Kts}$$

Now we have the speed of climb:

$$R_{Climb} = 111.52 \text{ nm}$$

Now with climb range we can calculate cruise range.

$$R_{Cr} = 6388.49 \text{ nm}$$

In Table 2.2 Roskam range of (L/D) Cruise for transport jet aircraft is given, then with using it (L/D) cruise mode can be guessed and using the following formula to check it and correct it.

$$\left.\frac{L}{D}\right)_{MAX} = 0.5\sqrt{\frac{\pi\, AR}{K\, C_{Df}}}$$

Some known parameters:

$$K=1.2$$

$$C_{Df} = 0.0165$$

$$AR = 9.813606827$$

And some to calculate:

$$\left.\frac{L}{D}\right)_{MAX} = \left.\frac{L}{D}\right)_{Loiter} = 0.5 \times \sqrt{\frac{\pi \times\ 9.813606827}{1.2 \times\ 0.0165}}$$

$$\left.\frac{L}{D}\right)_{Cruise} = 0.866 \left.\frac{L}{D}\right)_{Loiter}$$

$$\left.\frac{L}{D}\right)_{\text{Fly to alternate}} = 0.6 \left.\frac{L}{D}\right)_{MAX}$$

So:

$$\left.\frac{L}{D}\right)_{Cruise} = 17.08$$

$$\left.\frac{L}{D}\right)_{MAX} = 19.73$$

$$\left.\frac{L}{D}\right)_{\text{Fly to alternate}} = 11.835$$

According to calculations made and Mission, the amount of cruise weight fraction obtained using Breguet equations.

$$\frac{W_5}{W_4} = 0.7$$

4.1.4-Calculating Loiter to Cruise Weight

Using this formula to calculate loiter endurance:

$$E_{Loiter} = \frac{1}{C_{j_{Loiter}}} \times \frac{L}{D}\Big)_{Loiter} \times \ln\left(\frac{W_5}{W_6}\right)$$

According to the mission, endurance in this phase is 0.75 hour. In Roskam table, *Cj loiter must not exceed one unit of Cj During the cruise phase. Therefore, we consider 0.6 for Cj in loiter phase.
According to the information given in the definition of Mission, the amount of loiter to cruise weight is:

$$\frac{W_6}{W_5} = 0.977$$

4.1.5-Calculating Flying to Alternate Over Loiter Weight

To calculate the weight ratio of the phase Fly to alternate the following formula is used:

$$R_{Fly} = \left(\frac{V}{C_j}\right)_{Fly} \times \left(\frac{L}{D}\right)_{Fly} \times \ln\left(\frac{W_7}{W_8}\right)$$

According to the mission, range in this phase is equal to 300 nm and V and Cj are 250 Knots (according FAR25) and 0.9, respectively.
L/D in this phase is equal to 11.835:

$$\left(\frac{L}{D}\right)_{Fly} = 0.6\left(\frac{L}{D}\right)_{Loiter}$$

So then:

$$\frac{W_8}{W_7} = 0.913$$

4.1.6-Finalizing Mff

Due to the weight ratios calculated, now Mff can be calculated as follows:

$$M_{ff} = \frac{w_9}{w_8} \times \frac{w_8}{w_7} \times \frac{w_7}{w_6} \times \frac{w_6}{w_5} \times \frac{w_5}{w_4} \times \frac{w_4}{w_3} \times \frac{w_3}{w_2} \times \frac{w_2}{w_1} \times \frac{w_1}{w_{T.O}} = 0.586$$

Fuel weight can be obtained from:

$$W_F = (1 - M_{ff})W_{T.O} + K(1 - M_{ff})W_{T.O}$$

Assuming that $W_{F_{Reserve}}$ is a fraction of F_{Used} then as defined in Roskam this fraction is 0.25,now:

$$W_{F_{Reserve}} = 0.25F_{Used}$$

So the equation has led to:

$$W_{F_{Guessed}} = 1.25(1 - M_{ff})W_{T.O}$$

$$W_{F_{Guessed}} = 388125\text{lbs}$$

4.2-Finalizing Take-Off Weight

Now it's time to get what we wanted from the first place!

4.2.1-Calculating Operating Empty Weight (Tent)

$W_{OE_{tent}}$ can be obtained from the following formula:

$$W_{OE_{tent}} = W_{T.O} - W_F - W_{PL} = 267875\ lbs$$

4.2.2-Calculating Empty Weight (Tent)

Also for the temporary experimental W_E we can use this formula:

$$W_{E_{tent}} = W_{OE_{tent}} - 0.005(W_{T.O}) - W_{Crew}$$

And the crew weight was:

$$W_{Cr} = 2050lbs$$

And the payload weight:

$$W_{PL} = 94000lbs$$

So in conclusion:

$$W_{E_{tent}} = 262075lbs$$

4.2.3-Allowable Amount of Empty Weight

4.2.3.1-Looking for A and B

In this stage to calculate the value of W_E we need A and B. To obtain the values of A and B logarithmic graph $W_{T.O} - W_E$ for the data base in Excel should be drawn. from The points obtained in this chart, we draw a line that equation gives us A and B values and they should be close to The amounts in the table 1.52 of Roskam book.

A and B values are 0.0833 and 1.0383, respectively for a transport jet aircraft.

4.2.3.2- A and B Graph

First, charting $logW_{T.O}\ vs\ log\ W_E$ for all the planes in the data base, values for A and B Roskam was far from normal values. That's why we have to remove some peer aircrafts data. By deleting some data from peer planes A and B were as follows:

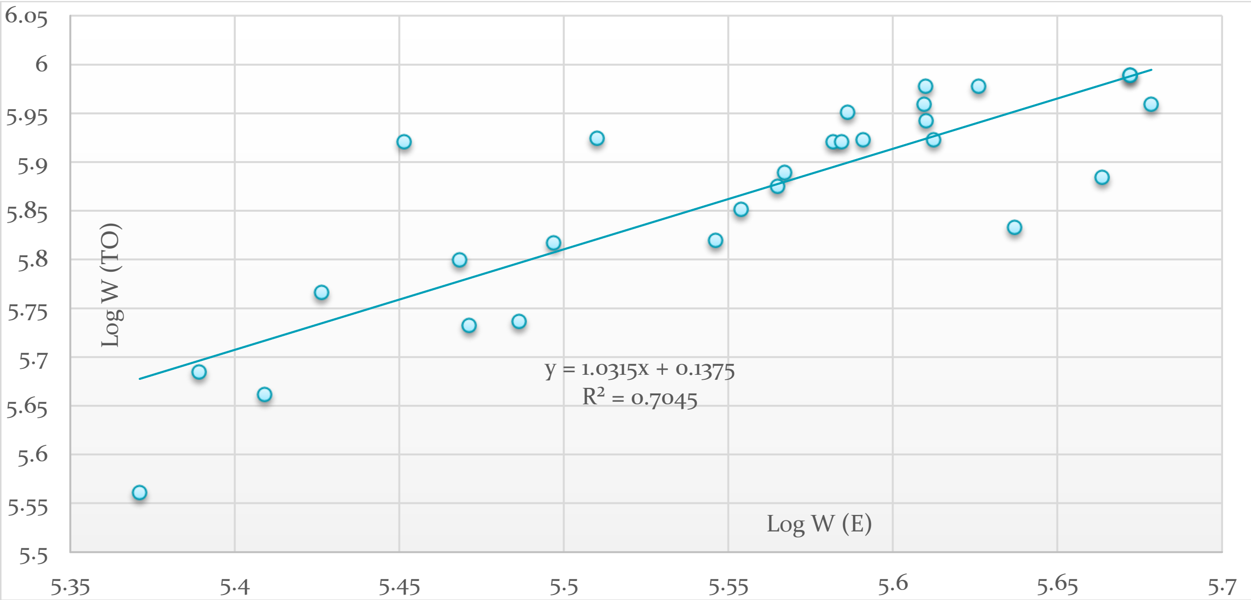


Figure 1 Log ($W_{T.O}$) vs Log (W_E)

$$\log W_{T.O} = 1.0315 \log W_E + 0.1375$$

4.2.3.3-Finding the Exact Allowable Empty Weight

According to A and B obtained, allowable W_E is obtained from the following formula:

$$W_E = inv\log\left(\log\frac{W_{T.O} - A}{B}\right) = 268150.6\ lbs$$

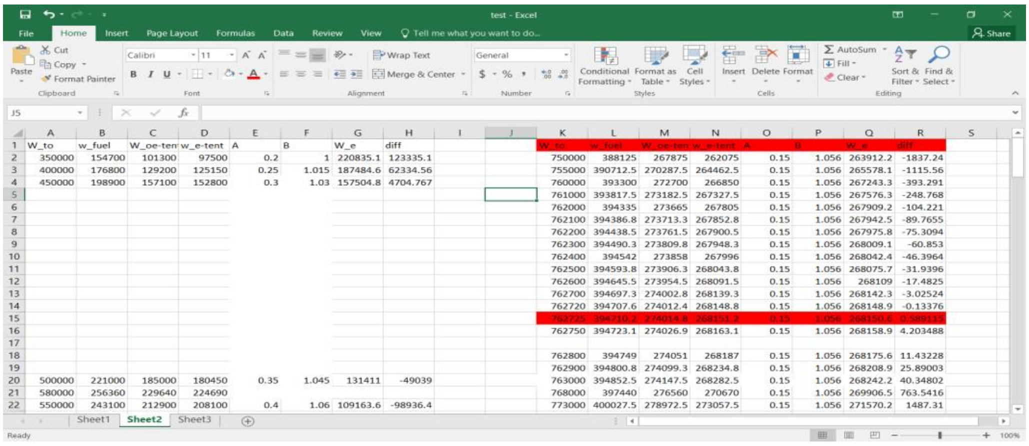
4.2.4-Finalizing Take-Off Weight

Finally, we should obtain error percentage difference between the amount of allowable and tented W_E.

Optimum take-off weight of aircraft should be close to the target (B777-300ER) and the margin of error is under 0.5%.

But with A and B obtained from peer aircrafts data base, margin of error below 0.5% is above from the target planes weight which its error percentage difference was too far from target aircraft weight.

But because of 30% graphs error, numbers for A and B, are not accurate. As a result, we have to manually reach to a minimum error.



W_to	w_fuel	W_oe-ten	w_e-tent	A	B	W_e	diff
750000	388125	267875	262075	0.15	1.056	263912.2	-1837.24
755000	390712.5	270287.5	264462.5	0.15	1.056	265578.1	-1115.56
760000	393300	272700	266850	0.15	1.056	267243.3	-393.291
761000	393817.5	273182.5	267327.5	0.15	1.056	267576.3	-248.768
762000	394335	273665	267805	0.15	1.056	267909.2	-104.221
762100	394386.8	273713.3	267852.8	0.15	1.056	267942.5	-89.7655
762200	394438.5	273761.5	267900.5	0.15	1.056	267975.8	-75.3094
762300	394490.3	273809.8	267948.3	0.15	1.056	268009.1	-60.853
762400	394542	273858	267996	0.15	1.056	268042.4	-46.3964
762500	394593.8	273906.3	268043.8	0.15	1.056	268075.7	-31.9396
762600	394645.5	273954.5	268091.5	0.15	1.056	268109	-17.4825
762700	394697.3	274002.8	268139.3	0.15	1.056	268142.3	-3.02524
762720	394707.6	274012.4	268148.8	0.15	1.056	268148.9	-0.13376
762725	394710.2	274014.8	268151.2	0.15	1.056	268150.6	0.589115
762750	394723.1	274026.9	268163.1	0.15	1.056	268158.9	4.203488

A=0.15 B=1.056

So in conclusion:

$$W_{TO} = 762725 lbs$$

$$W_E = inv\,log\left(log\frac{W_{T.O} - A}{B}\right) = 268150.6\ lbs$$

$$W_{fuel} = 1.25(1 - 0.586) \times 762725$$

$$W_{OE\ tent} = 762725 - W_{fuel} - (W_{PL} = 94000)$$

$$W_{E\ tent} = W_{OE\ tent} - (0.005 \times 762725) - (W_{Crew} = 2050)$$

W_{TO}	W_{fuel}	$W_{OE\ tent}$	$W_{E\ tent}$	A	B	W_E	Diff
762725	394710.2	274014.8	268151.2	0.15	1.056	268150.6	0.589115

4.2.6-Table of Calculations

Take Off Weight	
$W_{T.O_{Guess}}$	$680000\ lbs$
V	$V_{Cr} = 482.27$
	$V_{T.O} = 186.83$
	$V_{Cl} = 334.55$
	$V_{Fly} = 250$
R	$R_{Cl} = 111.51$
	$R_{Cr} = 6388.49$
	$R_{Fly} = 300$
C_j	${C_j}_{Cr} = 0.46$
	${C_j}_{Loiter} = 0.6$
	${C_j}_{Fly} = 0.9$
$\frac{L}{D}$	$\left.\frac{L}{D}\right)_{Cr} = 17.08$
	$\left.\frac{L}{D}\right)_{Loiter} = 19.73$ $\left.\frac{L}{D}\right)_{Fly} = 11.835$
$Weight\ Ratio$	$\left.\frac{W_5}{W_4}\right)_{Cr} = 0.7$
	$\left.\frac{W_6}{W_5}\right)_{Loiter} = 0.977$

	$\left.\frac{W_8}{W_7}\right)_{Fly} = 0.913$	
M_{ff}	0.586	
W	$W_{F_{used}} = 374710.2$	
	$W_{Pl} = 94000$	
	$W_{Cr} = 2050$	
W_{tent}	$W_{OE_{tent}} = 274014.8$	
	$W_{e_{tent}} = 268151.2$	
$A\,,B\ (Calculate)$	$A = 0.1375$	
	$B = 1.0315$	
$A\,,B\ (Changed)$	$A = 0.15$	
	$B = 1.056$	
$W_{T.O}$	762725	
$ERROR$	0.589115	

5-Second Step

Now that we have reached an amount of take-off weight, we should do some research about its sensitivity to other parameters, so we can optimum the sizing's.

5.1-Sensetivity Studies

It is quite obvious that sensitivity of $W_{T.O}$ to W_{PL} is really important, because as you know, all of our point for building this airplane is to move some payload and make money out of it! So as you can see having more and more payload is what we want, but we don't want our aircraft to crash either! That's why this sensitivity is very serious.

Let's start:

5.1.1-Sensetivity of Take-Off to Payload Weight

Roskam book formula 2.27 for takeoff weight to payload weight is:

$$\frac{\partial W_{T.O}}{\partial W_{PL}} = \frac{BW_{T.O}}{D - C(1-B)W_{T.O}}$$

$$B = 1.056$$

And:

$$W_{TO} = 762725$$

Then:

$$C = 1 - (1 - M_{ff}) - M_{TFO}$$
$$D = W_{PL} + W_{Cr}$$

$$M_{ff} = 0.586$$

$$M_{TFO} = 0.005$$

According to the mission we defined for W_{PL} and W_{Cr}:

$$W_{PL} = 94000\ lbs$$

$$W_{Cr} = 2050\ lbs$$

As a result, the amount of C and D become as follow:

$$C = 0.581$$

$$D = 96050$$

Then, sensitivity of take-off weight to payload weight is obtained:

$$\frac{\partial W_{T.O}}{\partial W_{PL}} = 6.663887799$$

This number shows us that take-off weight is a lot sensitive about payload weight. in fact, for example, if we put 1 pound more of payload on, the take-off weight will rise for 6.6638 pounds, which is a lot.so we should be careful of rising the payload weight.

Let’s see what happens for other parameters:

5.1.2-Sensetivity of Take-Off to Empty Weight

Using the formula 2.29 from Roskam book, $\frac{\partial W_{T.O}}{\partial W_E}$ calculated as follows:

$$\frac{\partial W_{T.O}}{\partial W_E} = \frac{BW_{T.O}}{\ln V \log\left[\frac{\log W_{T.O} - A}{B}\right]}$$

And for:

A=0.15 and B=1.056

Then we have:

$$\frac{\partial W_{T.O}}{\partial W_E} = 3.00367631$$

So empty weight is not as sensitive as payload weight but it is quite important.

And again for more parameter we have:

5.1.3-Sensetivity of Take-Off Weight to Range, Endurance, Velocity, SFC and L/D

The parameters range (R), endurance (E), SFC (Cj) and L / D with Y icon will be displayed.

First, we need to calculate sensitivity coefficient F:

C=0.581 and D=96050

$$F = \frac{-BW_{TO}{}^{2}(1 + M_{Res})M_{ff}}{CW_{T.O}(1 - B) - D}$$

According to Mff and B and W_{TO} obtained in the previous stage and calculated C and D, we have:

$$F = 3723087.874 \ lbs$$

Due to the changes of values, range (R), speed (V), SFC (Cj) and L/D in every phase it is necessary to evaluate the sensitivity of take-off weight to every one of these parameters in all phases.

5.1.4-Sensetivity of Take-Off Weight in Cruise Phase

Using the data obtained in the previous stage which are cruising speed V(Cr), cruise range R(Cr), Cj and L/D (Cr):

$$V_{Cr} = 482.27 \ knots$$

$$R_{Cr} = 6388.49 \text{ nm}$$

$$C_{j\,Cr} = 0.46$$

$$\frac{L}{D}_{Cr} = 17.08$$

During the cruise phase sensitivity of the above mentioned parameters using formulas in the following table (according to Roskam), is calculated:

Cruise		
$Y=R$	$\frac{\partial \bar{R}}{\partial Y}=C_j\left(V\frac{L}{D}\right)^{-1}=5.584441145E^{-5}$	$\frac{\partial W_{T.O}}{\partial Y}=F\times\frac{\partial \bar{R}}{\partial Y}=207.9136511$
$Y=C_j$	$\frac{\partial \bar{R}}{\partial Y}=R\left(V\frac{L}{D}\right)^{-1}=0.7755684$	$\frac{\partial W_{T.O}}{\partial Y}=F\times\frac{\partial \bar{R}}{\partial Y}=2887509.306$
$Y=V$	$\frac{\partial \bar{R}}{\partial Y}=-RC_j\left(V^2\frac{L}{D}\right)^{-1}=0.000739546273$	$\frac{\partial W_{T.O}}{\partial Y}=F\times\frac{\partial \bar{R}}{\partial Y}=-2754.171483$
$Y=\frac{L}{D}$	$\frac{\partial \bar{R}}{\partial Y}=-RC_j\left(V\left(\frac{L}{D}\right)^2\right)^{-1}=-0.020887673$	$\frac{\partial W_{T.O}}{\partial Y}=F\times\frac{\partial \bar{R}}{\partial Y}=-77766.64408$

5.1.5-Sensetivity of Take-Off Weight in Loiter Phase

Regarding the values of Endurance (E), ${C_j}_{Ltr}$ and L/D which have gained before from loiter phase, sensitivity of these parameters in loiter phase for takeoff weight are calculated as follows:

$$E_{Ltr}=0.75\ hr$$

$${C_j}_{Ltr}=0.6$$

$$\frac{L}{D}_{Ltr}=19.73$$

Loiter		
$Y=E$	$\frac{\partial \bar{E}}{\partial Y}=C_j\left(\frac{L}{D}\right)^{-1}=0.030410542$	$\frac{\partial W_{T.O}}{\partial Y}=F\times\frac{\partial \bar{E}}{\partial Y}=113221.1214$
$Y=C_j$	$\frac{\partial \bar{E}}{\partial Y}=E\left(\frac{L}{D}\right)^{-1}=0.038013177$	$\frac{\partial W_{T.O}}{\partial Y}=F\times\frac{\partial \bar{E}}{\partial Y}=141526.4017$
$Y=\frac{L}{D}$	$\frac{\partial \bar{E}}{\partial Y}=-EC_j\left(\frac{L}{D}\right)^{-2}=-0.00115601355$	$\frac{\partial W_{T.O}}{\partial Y}=F\times\frac{\partial \bar{E}}{\partial Y}=-4303.894628$

5.1.6-Sensetivity of Take-Off Weight in Fly to Alternate Phase

Using the speed and range V_{Fly} & R_{Fly} defined in the mission and Cj and L/D obtained, sensitivity of this phase are:

$$V_{Fly}=250\ knots$$

$$R_{Fly} = 300\ nm$$

$$C_{j_{Fly}} = 0.9$$

$$\frac{L}{D_{Fly}} = 11.835$$

Fly to alternate		
$Y = R$	$\frac{\partial \bar{R}}{\partial Y} = C_j\left(V\frac{L}{D}\right)^{-1} = 0.0003041825095$	$\frac{\partial W_{T.O}}{\partial Y} = F \times \frac{\partial \bar{R}}{\partial Y} = 1132.498213$
$Y = C_j$	$\frac{\partial \bar{R}}{\partial Y} = R\left(V\frac{L}{D}\right)^{-1} = 0.101394169$	$\frac{\partial W_{T.O}}{\partial Y} = F \times \frac{\partial \bar{R}}{\partial Y} = 377499.04042$
$Y = V$	$\frac{\partial \bar{R}}{\partial Y} = -RC_j\left(V^2\frac{L}{D}\right)^{-1} = -0.0003650190114$	$\frac{\partial W_{T.O}}{\partial Y} = F \times \frac{\partial \bar{R}}{\partial Y} = -1358.997855$
$Y = \frac{L}{D}$	$\frac{\partial \bar{R}}{\partial Y} = -RC_j\left(V\left(\frac{L}{D}\right)^2\right)^{-1} = -0.00771058326$	$\frac{\partial W_{T.O}}{\partial Y} = F \times \frac{\partial \bar{R}}{\partial Y} = -28707.17903$

Table of Sensitivities:

Sensitivity	
Last Step	$W_{T.O} = 762725$
	$W_{PL} = 94000$
	$W_{Cr} = 2050$
	$M_{TFO} = 0.005$
	$M_{ff} = 0.586$
	$A = 0.15$

<table>
<tr><td colspan="2"></td><td colspan="2">$B = 1.056$</td></tr>
<tr><td colspan="4">$W_{T.O} - W_{PL}$</td></tr>
<tr><td colspan="2">$C = 0.581$</td><td colspan="2" rowspan="2">$\frac{\partial W_{T.O}}{\partial W_{PL}} = 6.663887799$</td></tr>
<tr><td colspan="2">$D = 96050$</td></tr>
<tr><td colspan="4">$W_{T.O} - W_E$</td></tr>
<tr><td colspan="4">$\frac{\partial W_{T.O}}{\partial W_E} = 3.00367631$</td></tr>
<tr><td colspan="4">$F = 3723087.874$</td></tr>
<tr><td colspan="4">CRUISE</td></tr>
<tr><td>$Y = R$</td><td colspan="2">$\frac{\partial \bar{R}}{\partial Y} = C_j\left(V\frac{L}{D}\right)^{-1} = 5.584441145E^{-5}$</td><td>$\frac{\partial W_{T.O}}{\partial Y} = F \times \frac{\partial \bar{R}}{\partial Y} = 207.9136511$</td></tr>
<tr><td>$Y = C_j$</td><td colspan="2">$\frac{\partial \bar{R}}{\partial Y} = R\left(V\frac{L}{D}\right)^{-1} = 0.7755684$</td><td>$\frac{\partial W_{T.O}}{\partial Y} = F \times \frac{\partial \bar{R}}{\partial Y} = 2887509.306$</td></tr>
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</table>

LOITER		
$Y = E$	$\frac{\partial \bar{E}}{\partial Y} = C_j \left(\frac{L}{D}\right)^{-1} = 0.030410542$	$\frac{\partial W_{T.O}}{\partial Y} = F \times \frac{\partial \bar{E}}{\partial Y} = 113221.1214$
$Y = C_j$	$\frac{\partial \bar{E}}{\partial Y} = E \left(\frac{L}{D}\right)^{-1} = 0.038013177$	$\frac{\partial W_{T.O}}{\partial Y} = F \times \frac{\partial \bar{E}}{\partial Y} = 141526.4017$
$Y = \frac{L}{D}$	$\frac{\partial \bar{E}}{\partial Y} = -EC_j \left(\frac{L}{D}\right)^{-2} = -0.00115601355$	$\frac{\partial W_{T.O}}{\partial Y} = F \times \frac{\partial \bar{E}}{\partial Y} = -4303.894628$
Fly to alternate		
$Y = R$	$\frac{\partial \bar{R}}{\partial Y} = C_j \left(V \frac{L}{D}\right)^{-1} = 0.0003041825095$	$\frac{\partial W_{T.O}}{\partial Y} = F \times \frac{\partial \bar{R}}{\partial Y} = 1132.498213$
$Y = C_j$	$\frac{\partial \bar{R}}{\partial Y} = R \left(V \frac{L}{D}\right)^{-1} = 0.101394169$	$\frac{\partial W_{T.O}}{\partial Y} = F \times \frac{\partial \bar{R}}{\partial Y} = 377499.04042$
$Y = V$	$\frac{\partial \bar{R}}{\partial Y} = -RC_j \left(V^2 \frac{L}{D}\right)^{-1} = -0.0003650190114$	$\frac{\partial W_{T.O}}{\partial Y} = F \times \frac{\partial \bar{R}}{\partial Y} = -1358.997855$
$Y = \frac{L}{D}$	$\frac{\partial \bar{R}}{\partial Y} = -RC_j \left(V \left(\frac{L}{D}\right)^2\right)^{-1} = -0.00771058326$	$\frac{\partial W_{T.O}}{\partial Y} = F \times \frac{\partial \bar{R}}{\partial Y} = -28707.17903$

6-Third Step

From now, we are going to look for Matching Diagram (a graph for T/W vs W/S) for all important configurations. This diagram helps a lot; it would show how much thrust do we need in every single configuration.it would show the proper amount of T/W.

For a start, we are now going to research about stall situation of our aircraft, which means the minimum of speed and maximum of $C_{l_{max}}$.

Now we are going to see what happens to T/W if we got into a stall situation:

6.1-Stall Sizing

To obtain $W/_S$ *stall* the relation (3.1) we have from Roskam books is:

$$V_S = \left(2\left(W/_S\right)/_\rho \; C_{l_{max}}\right)^{1/2}$$

V_S is the same as target airplane which is 170 knots.

Because the only stall speed in case we found is Vs(CLEAN) then we have to detect only in clean configuration whom stall speed is 170 knots.

$C_{l_{max}}$ according to Table 3.1 Roskam book for Take Off and Landing obtained, we have 1.2-1.8 for clean and 1.6-2.2 for take-off and 1.8-2.8 for landing configuration. There is something you should know, our reference book is kind of old, technology is enhancing every single day, so it's a bit better if we raise this type of Roskam's numbers a bit, it's on you how much!

Airport of origin: Kerman airport at an altitude of 1705 m (5594 ft) above sea level and the air temperature is 100 degrees Fahrenheit.

Now we have to obtain density value in both origin and destination airport which in this case are the same as each other! So:

$$\rho_{T.O} \& \rho_L = \sigma \times \rho_{S.L}$$

$$\sigma = \frac{\delta}{\theta}$$

$$\delta = \frac{P_{5594}}{P_{S.L}}$$

$$\theta = \frac{T_{5594}}{T_{S.L}}$$

Get pressure ratio δ:

$$P_{S.L} = 14.7 \text{ Psi}$$

Interpolation is obtained from standard table for P=5594 ft

P(psi)	h (ft)
12.1	5000
11.7	6000

Then:

$$P_{5594} = 11.8624 \; Psi$$

$$\delta = 0.806965986$$

Temperature ratio θ:

$$T_{S.L} = 288.16\ K = 518.688\ R$$

And from the mission:

$$T_{5594\ ft} = 100°\mathrm{F} = 559.67\ R$$

Then:

$$\theta = \frac{559.67}{518.688} = 1.079010889$$

Pressure and temperature coefficients are calculated then using them to find ratio of density σ:

$$\sigma = \frac{\delta}{\theta} = 0.747875664$$

Since the chance of getting into stall is much more for take-off and landing situations, we only study these two cases.

6.1.1-Clean Take-Off Configuration

Stall sizing calculations are usually evaluated at the airport because planes stall mostly in landing or take-off, in order to do this, we need to find the density of Kerman airport, the airport location. so:

At 5594 ft:

$$\rho/\rho_{S.L} = 0.747875664$$

$$\rho_{S.L} = 0.002377$$

$$\rho = 0.001777700453\ \mathrm{slug/ft^3}$$

In order to find W/S in clean configuration (flaps up) we obtain:

$$C_{L_{max_{clean}}} = 1.2 \text{ to } 2.2$$

$$V_S = 170 \text{ knots} = 286.928 \text{ ft/s}$$

$$V_S = (2(W/S)/\rho C_{L_{max}})^{1/2}$$

$$\left.\frac{W}{S}\right)_S = \frac{1}{2} V_{Stall}^2 \rho\ C_{L_{Max}} = 73.176974512217 C_{L_{Max}}$$

6.1.2-Clean Landing Configuration

Destination Airport: Kerman Airport at an altitude of 1705 m (5594 ft) above sea level and air temperature of 100 degrees Fahrenheit. And we already have destination airport density.

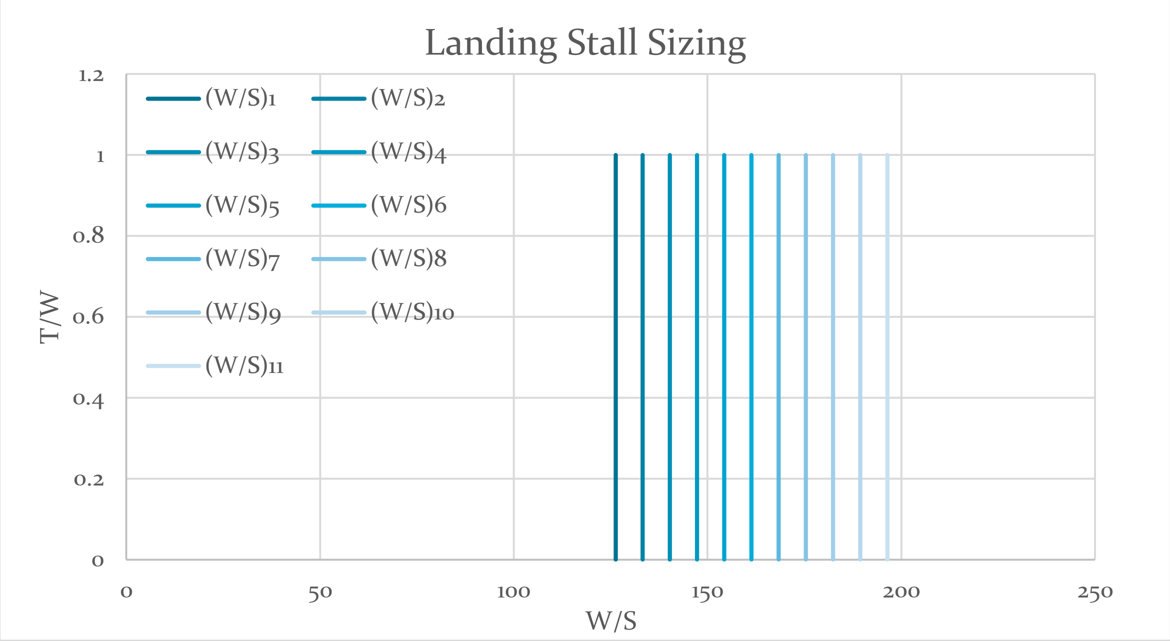
W/S has the following formula to be calculated:

$$\left.\frac{W}{S}\right)_S = \frac{1}{2} V_{Stall}^2 \rho\ C_{L_{Max}}$$

$$With\ C_{L_{Max\,T.O}} = 2.2 \quad \frac{W}{S} = 160.9893441$$

$$With\ \ C_{L_{Max\,L}} = 3 \quad \frac{W}{S} = 196.4159148$$

And having these ratios can be used to draw the graphs we were looking for.



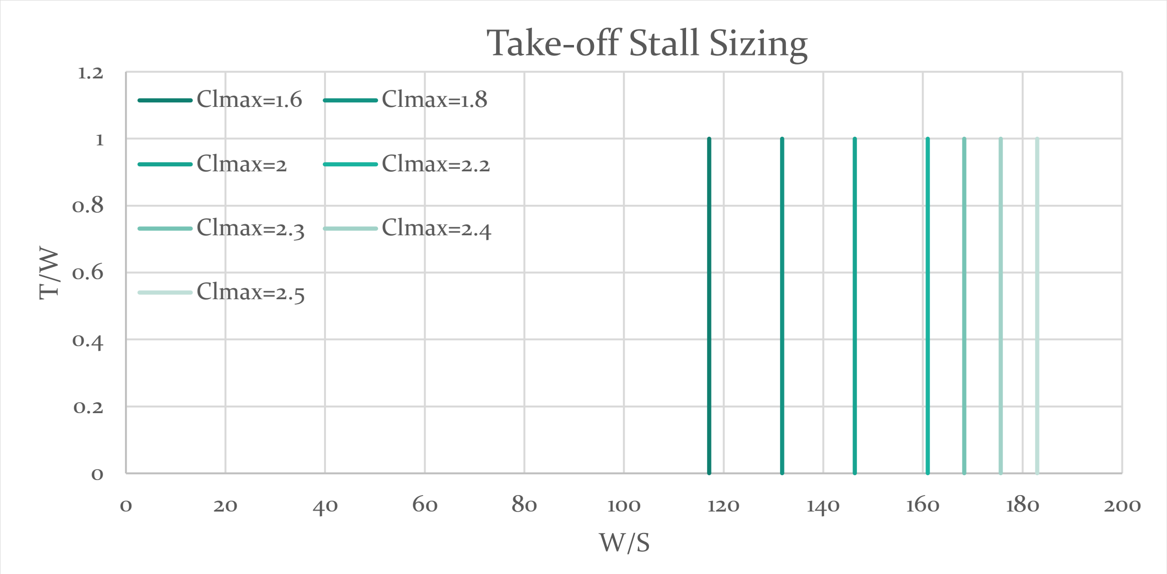


Figure 2 Landing and Take-off Sizing for Stall

7-Fourth Step

Stall sizing is over and now it's time for take-off, it wouldn't be wrong if we say that take-off phase and its sizing is a bit more important than the other phases, because everything starts from this phase and all off the flight phases are relevant to take-off, so we suggest you to take all safety factor and judgment you want in this phase. Let's begin:

7.1-Take-Off Sizing

To get started, we refer to the equation of distance of take-off bond in Far25:

$$S_{TOFL} = 37.5 \, {(W/S)_{TO}} \Big/ {\sigma C_{l_{maxTO}} (T/W)_{TO}}$$

S_{TOFL} from the mission is:

$$S_{TOFL} = 10500\, ft = 1.7280778\, nm$$

$C_{l_{T.O}}$ can be calculated from Table 3.1 of the reference book (Roskam) and taking into account the relevant numbers (range from 1.6 to 2.2), and as before taking credit for the advancement of technology and the rise of such factors during this years, we define the values. The range includes three numbers (again for range of 1.6 to 2.2), three distinct extraction ratio will be achieved, and of course with a value for σ in stall sizing step, which was 0.747875664, the following ratio can be achieved:

$$\sigma = 0.747875664$$

$$C_{l_{maxTO}} = 2.4 \text{ Then } {(T/W)_{TO}} \Big/ {(W/S)_{TO}} = 0.001989762884$$

$$C_{l_{T.O}} = 2.2 \text{ Then } {(T/W)_{TO}} \Big/ {(W/S)_{TO}} = 0.002170650419$$

$$C_{l_{T.O}} = 1.6 \text{ Then } {(T/W)_{TO}} \Big/ {(W/S)_{TO}} = 0.002984644326$$

And as before with having these ratios we can draw the graphs we still want!

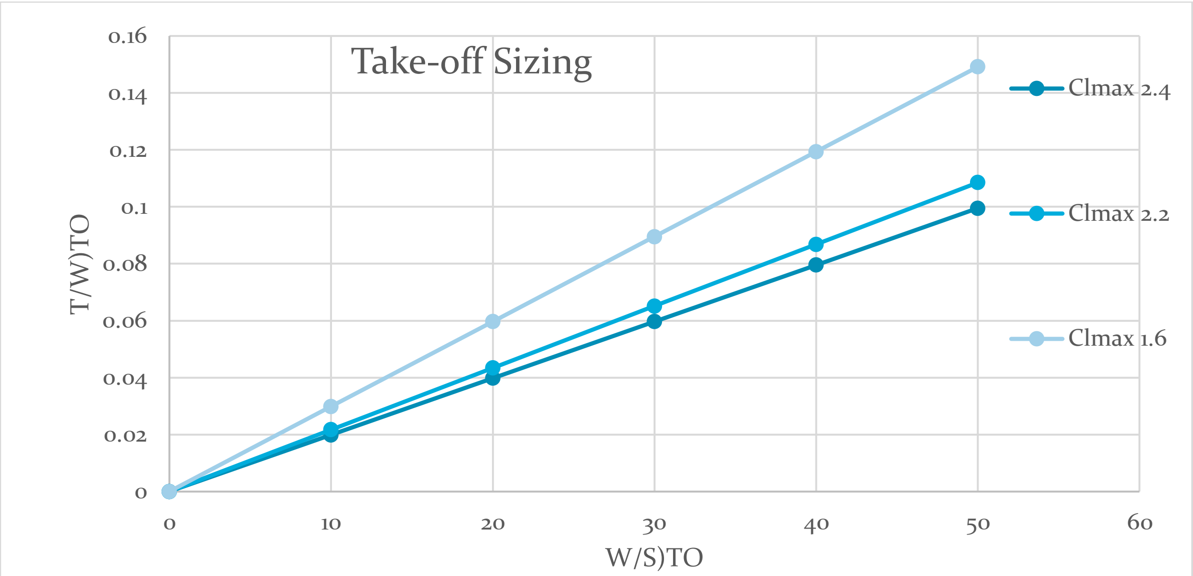


Figure 3 Take-off Sizing

8-Fifth Step

Now we need all the above parameters for landing phase:

8.1-Landing Sizing

According to the S_L related to the mission from the list defined, can be S_{FL} amount calculated according to the equations for Far 25.

$$S_{FL} = \frac{S_L}{0.6}$$

$$S_{FL} = \frac{8000}{0.6} = 13333.3\ ft$$

After S_{FL} we also find:

$$S_{FL} = 0.3V_A^2$$

$$V_A = \sqrt{\frac{S_{FL}}{0.3}} = \sqrt{\frac{13333.33}{0.3}} = 210.8185107\ Kts = 355.8215155964358587\ ft/s$$

V_A can be calculated, continue using the following formula, the amount of V_S which is the stall speed that may occur during landing, obtains.

$$V_A = 1.2\ V_S$$

$$V_S = \frac{210.8185107}{1.2} = 175.6820922\ \ Knots = 296.51792966369765736\ \ ft/s$$

And now because we've got the value of V_S, we use this general formula mentioned below, we'll see.

$$V_S = \left({}^{2\left({}^{W}/_{S}\right)}/_{\rho}\ C_{l_{max}} \right)^{1/2}$$

$$W/_S = \frac{\rho\ C_{l\ max}\ V_S\text{^}2}{2}$$

In this matter, the insertion of ρ at the destination airport which was 0.001777700453, sizing Stall calculated, and also taking into account the range includes four members for $C_{l_{\max}}$ in Roskam book Table 3.1, and as always based on advances in technology and other factors, some changes would be necessary.

We can now obtain 4 values for W/S:

$$C_{l_L} = 1.8 \text{ Then } \left(\frac{W}{S}\right)_L = 140.6671776$$

$$C_{l_L} = 2.3 \text{ Then } \left(\frac{W}{S}\right)_L = 179.7413937$$

$$C_{l_L} = 2.8 \text{ Then } \left(\frac{W}{S}\right)_L = 218.8156097$$

$$C_{l_{max_L}} = 3.0 \text{ Then } \left(\frac{W}{S}\right)_L = 234.4452961$$

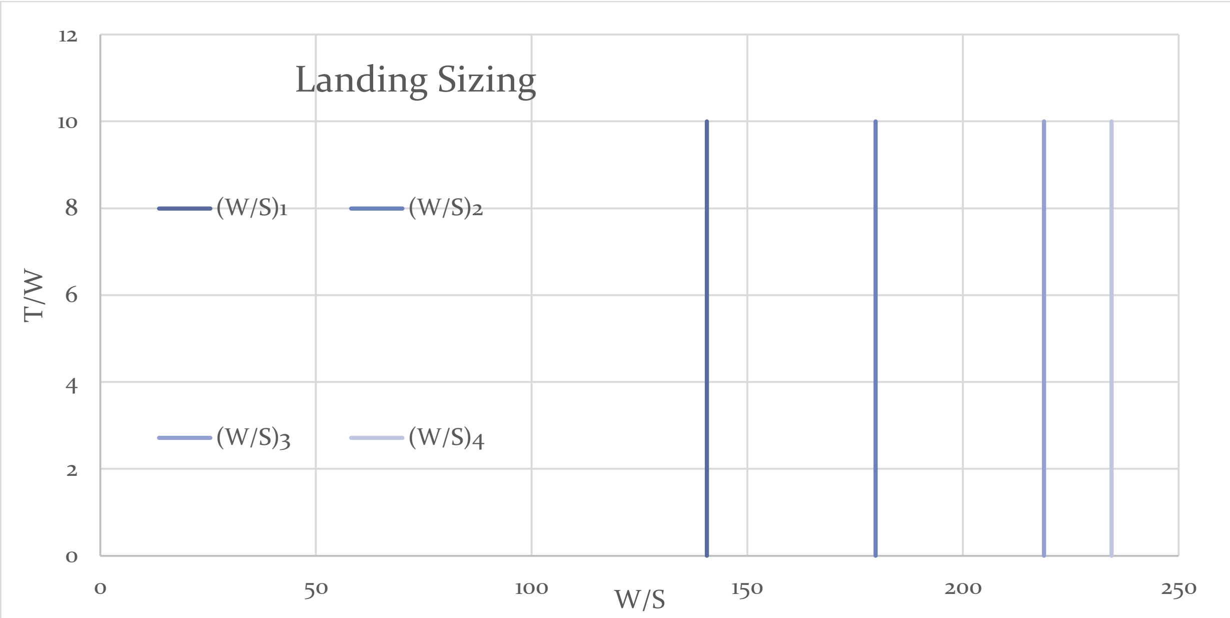


Figure 4 Landing Sizing

9-Sixth Step

We've now reached the climb phase, because of the nature of this flight phase, we can't talk generally for all of it in all the times, we need to divide it into six configurations, and talk about them one by one, and also in this step we need aircraft drag polar, because the difference between these situations is in the aircraft drag.

9.1-Climb Sizing

First we name the configurations we talked about and then aircraft Drag Polar Equation will be determined for each one of them.

- take off flaps, gear down
- take off flaps, gear up
- take off flaps, gear up, no ground effect
- clean configuration
- approach flaps, gear down
- landing flaps, gear down

Aircraft drag polar equation is obtained through the following relations:

$$C_D = C_{D_0} + kC_L^2$$
$$k = \frac{1}{\pi\ e\ AR}$$

To obtain the noise coefficient of drag (C_{D_0}) equation 3.20 of Roskam book will be used:

$$C_{D_0} = {}^{f}/_{s}$$

S is the area of the wing which is 4605 ft^2 (target airplane) and f is surface fraction that would be obtained from:

$$\log_{10} f = a + b \log_{10} S_{wet}$$

In the above equation a and b are a function of surface friction coefficient C_f, the value of C_f will be obtained from Figure(B) in Page 120 of the Roskam book, for a turbojet aircraft, it is considered 0.003. $C_f = 0.003$

Using Table 3.4 of the Roskam book, a and b can be obtained for different surface frictions (C_f).

For $C_f = 0.003$, a= -2.5229 and b=1.

Then we calculate S_{wet} from the following equation:

$$\log_{10} S_{wet} = c + d \log_{10} W_{To}$$

d and c from Table 3.5, of the Roskam book are 0.0199 and 0.7531 respectively obtained for a turbojet aircraft and have fixed values. And W(TO)= 762725 lbs (had been done).

$$c = 0.0199 \ \&\ d = 0.7531$$

$$S_{wet} = 28178.07541\ ft^2$$

By calculating the S_{wet} , f is obtained:

$$f = 84.53008915\ ft^2$$

By calculating the f and having the s of the target aircraft, C_{D_0} is determined.

$$s = 4605 ft^2$$

$$C_{D_0} = \frac{f}{s} = 0.018356153$$

When calculating the drag polar term, ΔC_{D_0} is defined, which indicates the effect of flap and gear. So drag polar is the relationship we rewrite as follows:

$$C_D = C_{D_0} + \Delta C_{D_0} + \frac{C_L^2}{\pi e AR}$$

According to Table 3.6, Roskam book value ΔC_{D_0} and e can be obtained:

Configuration	ΔC_{D_0}	E
Clean	0	0.85
Take off flaps	0.010-0.020	0.80
Landing flaps	0.055-0.075	0.75
Landing gear	0.015-0.025	No effects

As before due to advances in technology, we determine the value of ΔC_{D_0}, For the calculation of C_D, we must obtain AR to the following formula:

$$AR = {b^2}/{S}$$

b and s according to the data base of the target aircraft (B777-300ER) are respectively 212.5833 ft and 4605 ft ^ 2. S=4605ft^2 & b=212.58333ft

$$AR = 9.813606827$$

Then k is obtained, we consider e as 0.85 (due to advances of technology), So:

$$k = \frac{1}{\pi ARe}$$

$$K = 0.038178843$$

The drag polar relation is to be obtained for the configurations we said before. These parameters were as the same in all of the configurations, but the drag polar isn't so it's Time to obtaining Drag Polar Equations for all of them.

First: Take-off Flaps, gear up

$$C_D = C_{D_0} + \Delta C_{D_{0To\ Flaps}} + KC_l^2$$

$$C_D = 0.030356153 + 0.038178843C_l^2$$

Second: Take-off Flaps ,gear down

$$C_D = C_{D_0} + \Delta C_{D_{0To\ Flaps}} + \Delta C_{D_{0Landing\ Gear}} + KC_l^2$$

$$C_D = 0.046356153 + 0.038178843\ C_l^2$$

Third: Clean

$$C_D = C_{D_0} + KC_l^2 = 0.018356153 + 0.038178843\ C_l^2$$

Fourth: Approach flaps, Gear Down

$$C_D = C_{D_0} + \frac{\Delta C_{D_{0_{To\ Flap}}} + \Delta C_{D_{0_{Landing\ Flap}}}}{2} + \Delta C_{D_{0_{Landing\ Gear}}} + KC_l^2$$

$$C_D = 0.068856153 + 0.038178843\ C_l^2$$

Fifth: Landing Flaps ,Gear Down

$$C_D = C_{D_0} + \Delta C_{D_{0_{Landing\ Flap}}} + \Delta C_{D_{0_{Landing\ Gear}}} + KC_l^2$$

$$C_D = 0.091356153 + 0.038178843\ C_l^2$$

Now it's time to separately we T/W (remember we were looking for this as ever.).

First: Take-off Flaps, gear up, ground effect

In this case T/W is obtained from the following formula:

$$\left(\frac{T}{W}\right)_{T.O} = 2\left(\frac{1}{L/D} + 0.012\right)\ at\ 1.2\ V_{S_{T.O}}$$

To obtain the L/D, we read the $C_{l_{Max_{T.O}}}$ from Table 3.1 from the book Roskam for Take-off and due to technological advances took placed this years, we make the value a bit higher, for now we make it 2.4 . $C_{l_{Max_{T.O}}} = 2.4$

Now the lift coefficient for this flight conditions is:

$$C_{l_{TO}} = \frac{C_{l_{Max_{T.O}}}}{(1.2)^2} = 1.6666667$$

$C_{l_{TO}}$ obtained in relation to the drag polar, and then we obtain C_D for this flight condition:

$$C_D = 0.030356153 + 0.038178843 C_l^2$$

$$C_D = 0.136408494$$

Given the coefficients of lift and drag, L/D is calculated:

$$\frac{C_l}{C_D} = \frac{L}{D} = 12.21820297$$

Having obtained L/D so T/W can be calculated in this flight condition:

$$\left(\frac{T}{W}\right)_{T.O} = 0.187690206$$

T/W obtained is appropriate, for the temperature at airport but we need correction for temperature at every flying conditions. Based on Turbojet aircraft data and the example Roskam made for us, the temperature correction is 0.8. so T/W obtained, shall be divided by 0.8.

$$\left(\frac{T}{W}\right)_{T.O} = \frac{0.187690206}{0.8} = 0.234612757$$

Second: Take off Flaps, gear down, ground effect

In this step, as the first step works as follows:

$$\left(\frac{T}{W}\right)_{T.O} = 2\left(\frac{1}{L/D} + 0\right) \; at\ 1.1\ V_{S_{T.O}}$$

$$C_{l_{Lof}} = \frac{2.4}{(1.1)^2} = 1.983471074$$

$$C_D = 0.046356153 + 0.038178843\ C_l^2$$

$$C_D = 0.196557734$$

$$\frac{C_l}{C_D} = \frac{L}{D} = 10.09103551$$

$$\left(\frac{T}{W}\right)_{T.O} = 0.198195715$$

And taking into account its previous state, in this case T/W obtained should be divided by 0.8.

$$\left(\frac{T}{W}\right)_{T.O} = \frac{0.198195715}{0.8} = 0.247744644$$

Third: Take off Flaps ,gear up ,no ground effect

In this step, as are the cases acted before and the only difference in this case is that in this case with the first configuration of the aircraft is that in this case aircraft is not affected by the Ground Effect.

$$\left(\frac{T}{W}\right)_{T.O} = 2\left(\frac{1}{L/D} + 0.024\right) \; at\ 1.2\ V_{S_{T.O}}$$

$$C_{l_{Lof}} = \frac{2.4}{(1.2)^2} = 1.6666667$$

$$C_D = 0.030356153 + 0.038178843\ C_l^2$$

$$C_D = 0.13640894$$

$$\frac{C_l}{C_D} = \frac{L}{D} = 12.21816302$$

$$\left(\frac{T}{W}\right)_{T.O} = 0.211690728$$

And taking into account the first step, T/W divided by 0.8, we obtain.

$$\left(\frac{T}{W}\right)_{T.O} = \frac{0.211690728}{0.8} = 0.26461341$$

Forth: Clean

In this case we have to act like the steps before:

$$\left(\frac{T}{W}\right)_{T.O} = 2\left(\frac{1}{L/_D} + 0.012\right)\ at\ 1.25\ V_S$$

$$For\ C_{lmax} = 1.9\ \ Then\ \ C_l = \frac{1.9}{(1.25)^2} = 1.216$$

$$C_D = 0.018356153 + 0.038178843\ C_l^2 \quad \text{so} \quad C_D = 0.074809528$$

$$\frac{C_l}{C_D} = \frac{L}{D} = 16.25461398$$

$$\left(\frac{T}{W}\right)_{T.O} = 0.147041986$$

The T/W we have achieved is maximum continuous thrust. While the amount of acceptable for a turbojet aircraft is the Trust continued to maximum thrust at take-off that is 0.94. With this correction and temperature correction too, the following is obtained:

$$\left(\frac{T}{W}\right)_{T.O} = \frac{0.147041986}{0.94 * 0.8} = 0.195534557$$

Fifth: Approach Flaps ,gear down

Again we act like before:

$$\left(\frac{T}{W}\right)_L = \left(\frac{1}{L/_D} + 0.032\right)\ at\ 1.3\ V_{S_L}$$

$$C_l = \frac{3}{(1.3)^2} = 1.775147929$$

$$C_D = 0.068856153 + 0.038178843\ C_l^2$$

$$C_D = 0.18916342$$

$$\frac{C_l}{C_D} = \frac{L}{D} = 9.384202976$$

$$\left(\frac{T}{W}\right)_L = 0.138562059$$

To obtain $\left(\frac{T}{W}\right)_{T.O}$ in this configuration we should multiply $\left(\frac{T}{W}\right)_L$ to $\frac{W_L}{W_{TO}}$.

The $W_{T.O}$ was 762725 lbs and also W_L amount equals to the amount W_L of the target aircraft (B777-300ER) which is 544000 lbs, For temperature correction, the statement must be divided by 0.8. So $\left(\frac{T}{W}\right)_{T.O}$ is given by:

$$\left(\frac{T}{W}\right)_{T.O} = \frac{\left(T/W\right)_L \times W_L/W_{T.O}}{0.8} = 0.123533646$$

Sixth: Landing Flaps, gear down

As the fifth mode worked, follows with:

$$\left(\frac{T}{W}\right)_L = 2\left(\frac{1}{L/D} + 0.021\right)\ at\ 1.5\ V_{S_L}$$

$$C_l = \frac{3}{(1.5)^2} = 1.3333333$$

$$C_D = 0.091356153 + 0.038178843\ C_l^2 \rightarrow C_D = 0.159229651$$

$$\frac{C_l}{C_D} = \frac{L}{D} = 8.373649788$$

$$\left(\frac{T}{W}\right)_L = 0.280844476$$

Just like the fifth stage for weight correction and temperature correction, $\left(T/W\right)_L$ multiplied by the $W_L/W_{T.O}$ and division on 0.8.

$$\left(\frac{T}{W}\right)_{T.O} = \frac{\left(T/W\right)_L \times W_L/W_{T.O}}{0.8} = 0.250384141$$

And finally T/W to W/S in this section:

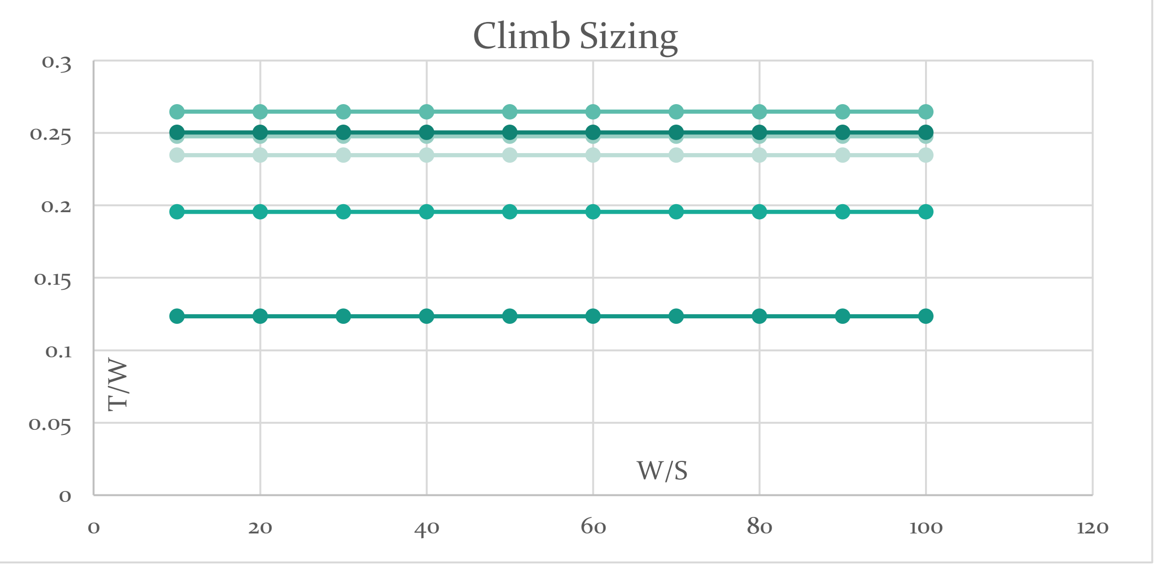


Figure 5 Climb Sizing

10-Seventh Step

Climb sizing is finally over, maneuvering sizing is going to start but keep in mind, it's a very tricky part and also not as much important! Why not important?! Because we are designing a commercial aircraft and it's not for maneuvering! By the way we need to do this anyway! So:

10.1-Maneuver Sizing

Vertical balance for Maneuver mode is achieved by Roskam book, relation 3.42.

$$nw = C_l\bar{q}s = 1482\delta M^2 C_l S$$

According to page 160 Roskam 3.43 relationship n_{Max} is achieved.

$$n_{Max} = \frac{1482\delta M^2 C_{l_{Max}}}{W/S}$$

From the mission:

$$M = 0.84$$
$$C_{l_{Max}} = 2\ (Table\ 3.1\ P91\ )$$
$$\delta = \frac{P_{35000ft}}{P_{S.L}} = 0.235374149$$

$$n_{Max} = \frac{492.2611186}{W/S}$$

And from Roskam 3.45 Equation:

$$\frac{T}{W} = \frac{\bar{q}C_{D_0}}{W/S} + \frac{W/S\,(n_{Max})^2}{\pi eAR}$$

$$\frac{T}{W} = \frac{4.48720761}{W/S} + \frac{37.8215899}{W/S}$$

$$\bar{q} = \frac{1}{2}\rho V^2 = \ 85.8236262201\text{knots} = 244.4859095$$
$$\rho_{35000\ ft} = 0.000738$$
$$C_{D_0} = 0.018356153\ (\ Climb\ Sizing\ )$$
$$V_{Cr} = 482.27(\ Weight\ \ Estimation)$$
$$AR = 9.813606827\ (\ Climb\ sizing\ )$$
$$e = 0.85$$

So then:

$$\frac{T}{W} = \frac{42.30941067}{W/S}$$

Now the graph:

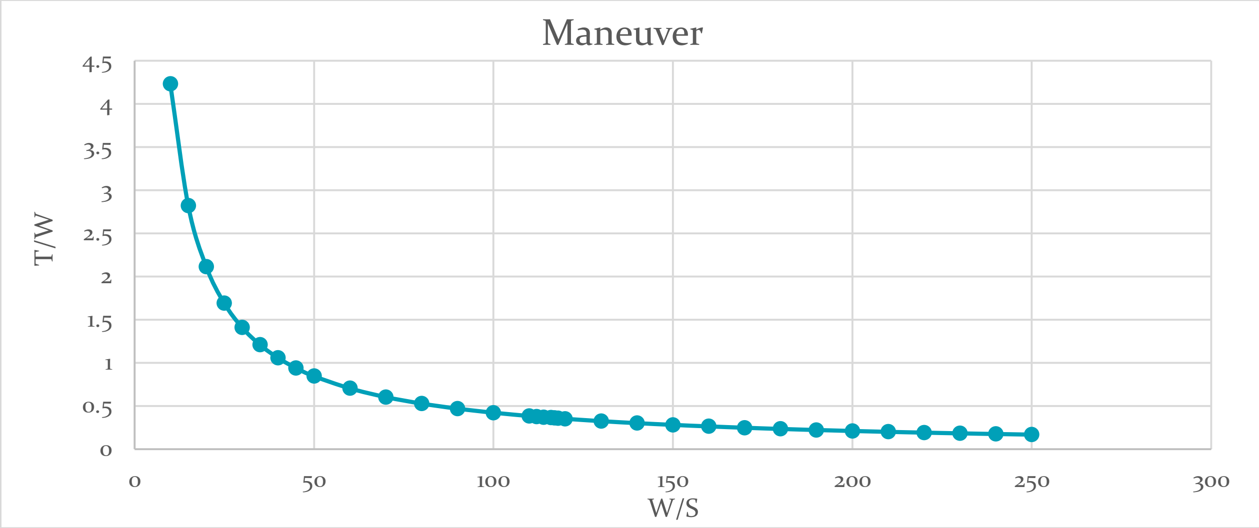


Figure 6 Maneuver Sizing

11-Eighth Step

Time to talk about cruise, we like to cruise in this job! Cruise is cheap, easy to reach, easy to design and doesn't tight our hands! So we like it and it's also a major part of time of the flight so its parameters are important. Let's see what happens:

11.1-Cruise Speed Sizing

We know Cruise is established as follows:

$$T = D = C_D \bar{q} S$$
$$W = L = C_l \bar{q} S$$
$$C_D = C_{D_0} + k C_L^2$$

Then:

$$T = C_{D_0} \bar{q} + \frac{C_L^2 \bar{q} S}{\pi e AR}$$

Therefore, by dividing the thrust-to-weight ratio of 3.60 T/W to W/S During the cruise phase of the relationship as follows Roskam obtained.

$$\frac{T}{W} = \frac{C_{D_0} \bar{q} S}{W} + \frac{W}{\bar{q} S \pi e AR} = \frac{C_{D_0} \bar{q}}{W/_S} + \frac{W/_S}{\bar{q} \pi e AR}$$

$$\rho_{35000\,ft} = 0.000738 \,{}^{Slug}/_{ft^3}$$
$$C_{D_0} = 0.018356153 \text{ (} Climb\ Sizing \text{)}$$
$$V_{Cr} = 482.27 \ = 813.98 \text{ ft/s} (Weight\ Stimation \text{)}$$
$$AR = 9.813606827 \text{ (} Climb\ sizing \text{)}$$
$$e = 0.85$$
$$\bar{q} = 244.4859095$$

So the ratio is calculated as follows, T/W to W/S is:

$$\frac{T}{W} = \frac{W}{S}\left(\frac{4.487820761}{\left(W/_{S}\right)^{2}} + 0.00015608\right)$$

And as always we draw the graphs:

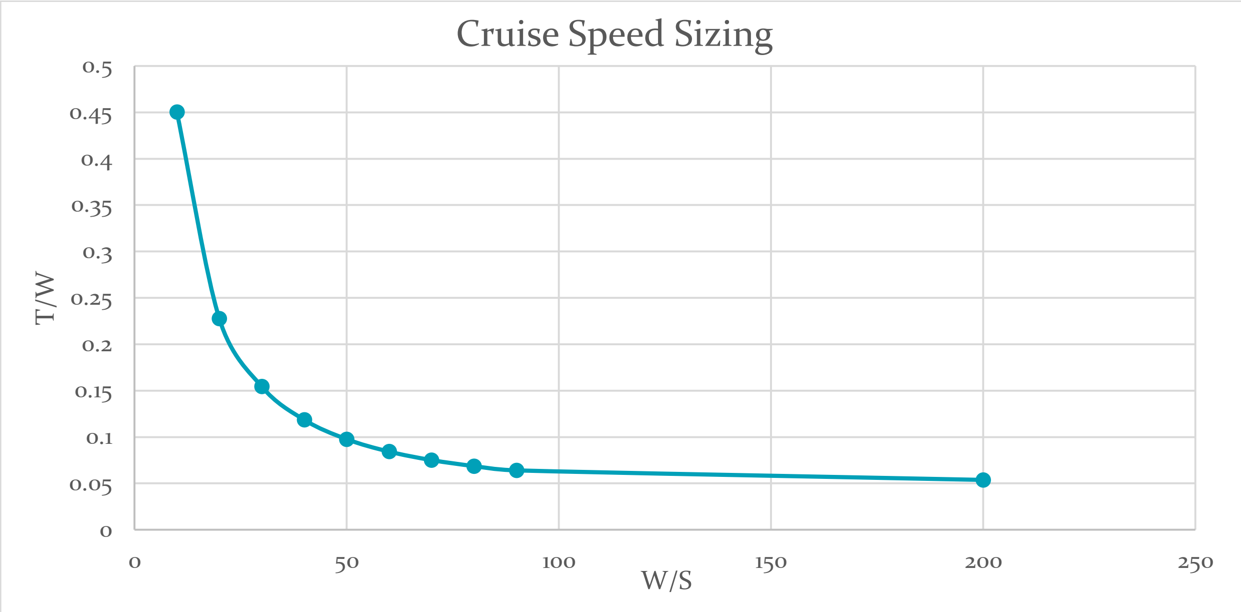


Figure 7 Cruise Speed Sizing

12-Ninth Step

In this step we talk about direct climb, it's all about how to reach the cruise height and what happens in the middle.

12.1-Direct Climb Sizing

Direct Climb splits into two parts, Sizing to ceiling and Time to climb.

12.1.1-Sizing to Ceiling

It's about reaching to ceiling height at the very ending of climb. And because of that, rate of climb is its maximum amount. The relation for $ROC)_{Max}$ is obtained from Roskam 3.4 equation:

$$ROC)_{Max} = V\left[\left(\frac{T}{W}\right) - \left(\frac{1}{\left(L/_{D}\right)_{Max}}\right)\right]$$

For the ROC at its maximum amount, shall be the maximum amount of L/D. L/D have gained maximum of 19.73 as we seen before. $\left(L/_{D}\right)_{Max} = 19.73$

The $ROC)_{Max}$ from Table 3.8 of the Roskam book, we should look for Minimum Required Climb Rate and determine it for the service ceiling.

$$ROC)_{Max} = 500\ {}^{ft}/_{m} = 8.333333\ {}^{ft}/_{s}$$

And the speed from above is obtained from the following formula:

$$V_{Cl} = \frac{V_{Cr} + V_{TO}}{2}$$

V_{Cl} =334.55 Knots =564.608 ft/s

Then:

$$\frac{T}{W} = \frac{(ROC)_{Max}}{V_{Climb}} + \frac{1}{({}^{L}/_{D})_{Max}} = 0.0654437399$$

T/W obtained should be divided by 0.23 to obtain the ratio of thrust to weight in takeoff mode.

$$\left(\frac{T}{W}\right)_{T.0} = \frac{0.0654437399}{0.23} = 0.2845379995652174$$

Thus, W/S to T/W graph is given in the form:

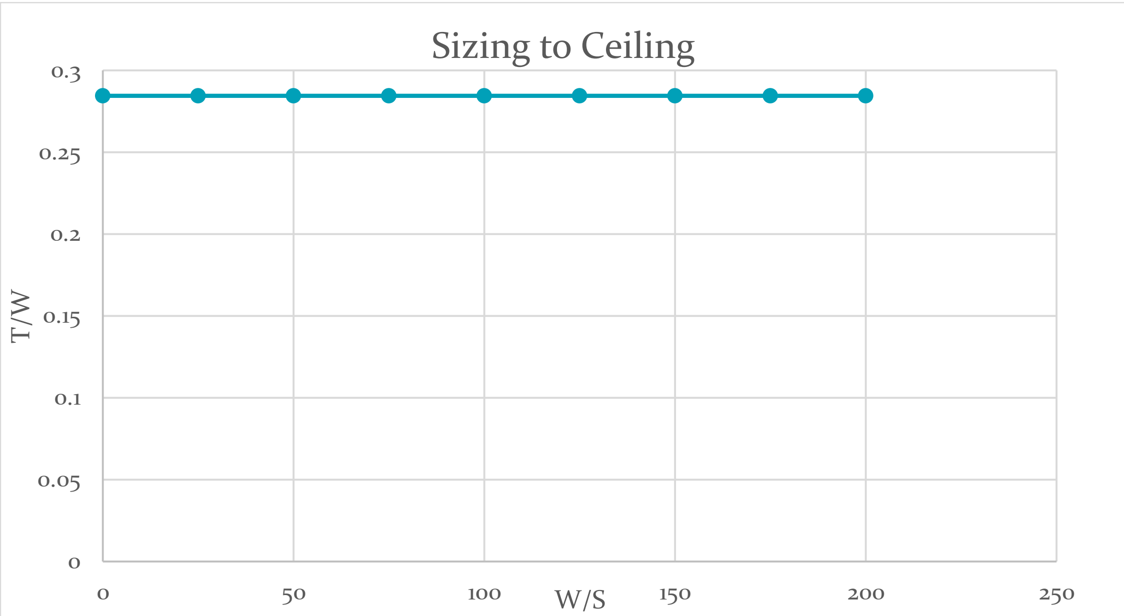


Figure 8 Sizing to Ceiling

12.1.3-Time to Climb

Now we are talking about the full phase of climbing, its process is identical with that one except that the value of ROC is given by the formula of Roskam 3.32.

$$ROC = ROC_0\left(1 - \frac{h}{h_{abs}}\right)$$

The ROC_0 amount Rate Of Climb in sea level, h ceiling of the mission are defined and h_{abs} absolute ceiling.

The ROC_0 3.34 Roskam the relationship is given by the formula:

$$ROC_0 = \frac{h_{abs}}{T_{Climb}} \ln\left(1 - \frac{h}{h_{abs}}\right)^{-1}$$

From the mission:

$$h = 35000\ ft$$
$$h_{abs} = 40000\ ft\ (\ Table\ 3.7\ P151\ )$$
$$T_{Climb} = 20\ \text{min} = 1200\ \text{Sec}$$

Then:

$$ROC_0 = 69.31471806\ \text{ft/s}$$

Therefore, the ROC will be given by:

$$ROC = 8.664339757\ ft/s$$

Finally, using the formula 3.34 and values of above, T/W will be obtained.

$$ROC = \left(\frac{2(W/_S)}{\rho(C_{D_0}\pi eAR)^{\frac{1}{2}}}\right)^{\frac{1}{2}}\left[\left(\frac{T}{W}\right) - \left(\frac{1}{L/_D}\right)\right]$$

$$\frac{T}{W} = \frac{ROC + \left(\frac{2(W/_S)}{\rho(C_{D_0}\pi eAR)^{\frac{1}{2}}}\right)^{\frac{1}{2}}\frac{1}{L/_D}}{\left(\frac{2(W/_S)}{\rho(C_{D_0}\pi eAR)^{\frac{1}{2}}}\right)^{\frac{1}{2}}} = \frac{ROC \times [\rho(C_{D0} \times AR \times \pi \times e)^{1/2}]^{1/2}}{\sqrt{2\,W/_S}} + \frac{1}{(L/_D)_{Max}}$$

And:

$$\left.\frac{L}{D}\right)_{Max} = 18.89224421\ (\ Cieling\ Sizing\ )$$
$$\rho_{5594\ ft} = 0.001777700453\ \ (\ Stall\ Sizing\ )$$
$$C_{D_0} = 0.018356153\ (\ Climb\ Sizing\ )$$
$$AR = 9.813606827\ (\ Climb\ Sizing\ )$$
$$e = 0.85$$

Then:

$$\frac{T}{W} = \frac{0.215126815}{(W/_S)^{\frac{1}{2}}} + 0.050684237$$

Finally, by dividing T / W to 0.23, W/S to T/W graph is given in the form.

$$\frac{T}{W} = \frac{0.935333979}{\left(W/_S\right)^{\frac{1}{2}}} + 0.220366248$$

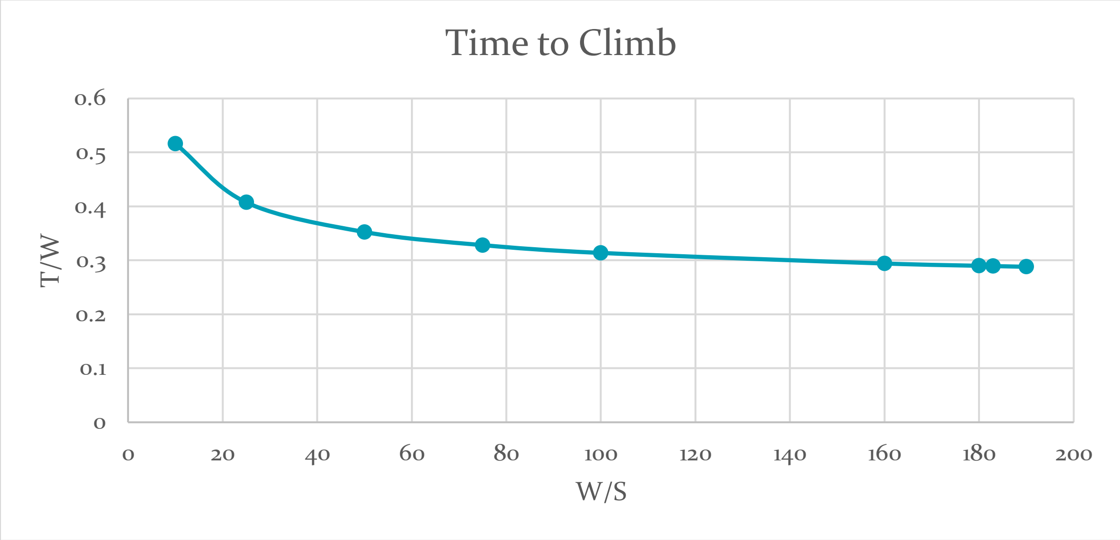


Figure 9 Time to Climb Sizing

Sizing's are all done, we just put them all in one table:

12.2- Sizing Tables

Stall Sizing	
P	$P_{S.L} = 14.7\ psi$
	$P_{5594\ ft} = 11.8624\ \ psi$
T	$T_{S.L} = 518.688\ K$
	$T_{5594\ ft} = 559.67\ K$
ρ	$\rho_{S.L} = 0.0023769$
	$\theta = 1.079010889$
	$\delta = 0.806965986$
	$\sigma = 0.747875664$
	$\rho_{T.O-L} = 0.001777700453$
C_L	$C_{L_{T.O}} = 2.2$
	$C_{L_L} = 3$
V_{Stall}	$V_{Stall_{clean}} = 286.928\ ft/s$

$\frac{W}{S}$	$\left(\frac{W}{S}\right)_{T.O} = 160.9893441$
	$\left(\frac{W}{S}\right)_{L} = 196.4159148$

Take Off Sizing	
$C_{l_{T.O}}$	$C_{l_{T.O_1}} = 2.4$
	$C_{l_{T.O_2}} = 2.2$
	$C_{l_{T.O_3}} = 1.6$
	$S_{TFOL} = 10500\ ft$
	$\sigma = 0.747875664$
$\frac{T/W}{W/S}$	$\left(\frac{T/W}{W/S}\right)_1 = 0.001989762884$
	$\left(\frac{T/W}{W/S}\right)_2 = 0.002170650419$
	$\left(\frac{T/W}{W/S}\right)_3 = 0.002984644326$

Landing Sizing	
C_{l_L}	$C_{l_{L_1}} = 1.8$
	$C_{l_{L_2}} = 2.3$
	$C_{l_{L_3}} = 2.8$
	$C_{l_{L_4}} = 3$
ρ_L	0.001777700453
S_L	$8000\ ft$
S_{FL}	$13333.3\ ft$
V_A	$355.8215155964358587\ {}^{ft}/_{s}$

V_S	$296.51792966369765736\, {}^{ft}/_{s}$
$\frac{W}{S}$	$\left(\frac{W}{S}\right)_1 = 140.6671776$
	$\left(\frac{W}{S}\right)_2 = 179.7413937$
	$\left(\frac{W}{S}\right)_3 = 218.8156097$
	$\left(\frac{W}{S}\right)_4 = 234.4452961$

Climb Sizing			
C_{D_0}			$S = 4605 ft^2$
			$b\ (Span) = 212.5833 ft$
			$C_f = 0.003$
			$a = -2.5229$
			$b = 1$
			$c = 0.0199$
			$d = 0.7531$
			$W_{T.O} = 762725\ lb$
			$S_{wet} = 28178.07541\ ft^2$
			$F = 84.53008915\ ft^2$
			$C_{D_0} = 0.018356153$
	ΔC_{D_0}	All Configuration e=0.85	$Take\ Off, Flaps, Gear\ Up = 0.012$
			$Take\ Off, Flaps, Gear\ Down = 0.028$
			$Take\ Off, Flaps, Gear\ Up,$ $No\ Ground\ Effect = 0.012$
			$Clean = 0$
			$Approach, Flaps, Gear\ Down = 0.0505$
			$Landing, Gear\ Down = 0.073$
			$AR = 9.813606827$

		K	K=0.038178843
		$C_{l_{Max}}$	$C_{l_{Max_{T.O}}} = 2.4$
			$C_{l_{Max_{Clean}}} = 1.9$
			$C_{l_{Max_L}} = 3$
		All Configuration	$Take\ Off\ , Flaps\ , Gear\ Up = 1.6666667$
			$Take\ Off\ , Flaps\ , Gear\ Down = 1.983471074$
			$Take\ Off\ , Flaps\ , Gear\ Up\ ,$ $No\ Ground\ Effect = 1.66666667$
			$Clean = 1.216$
			$Landing\ , Flaps\ , Gear\ Down = 1.775147929$
			$Approach\ , Gear\ Down = 1.3333333$
			$Clean = 1.216$
			$Landing\ , Flaps\ , Gear\ Down = 1.775147929$
			$Approach\ , Gear\ Down = 1.3333333$
	All Configuration $C_D = C_{D_0} + \Delta C_{D_0} + KC_l^2$		$Take\ Off\ , Flaps\ , Gear\ Up = 0.136408494$
			$Take\ Off, Flaps\ , Gear\ Down = 0.196557734$
			$Take\ Off\ , Flaps\ , Gear\ Up\ ,$ $No\ Ground\ Effect = 0.13640894$
			$Clean = 0.074809528$
			$Approach\ , Flaps\ , Gear\ Down = 0.18916342$
			Landing Flaps, $Gear\ Down = 0.159229651$
$\frac{T}{W}$	$\frac{L}{D}$		$Take\ Off\ , Flaps\ , Gear\ Up = 12.21820297$
			$Take\ Off, Flaps\ , Gear\ Down = 10.09103551$
			$Take\ Off\ , Flaps\ , Gear\ Up\ ,$ $No\ Ground\ Effect = 12.21816302$
			$Clean = 16.25461398$
			$Approach\ , Gear\ Down = 9.384202976$
			$Landing, Flaps\ , Gear\ Down = 8.373649788$

	Constant	$Landing\ , Flaps\ ,$ $Gear\ Down$	$\frac{W_L}{W_{T.O}} = 0.713232161$
		$Approach\ , Gear\ Down$	$\frac{W_L}{W_{T.O}} = 0.713232161$
	All Configuration	$Take\ Off\ , Flaps\ , Gear\ Up = 0.244781296$	
		$Take\ Off\ , Flaps\ , Gear\ Down = 0.247744644$	
		$Take\ Off\ , Flaps\ , Gear\ Up\ ,$ $No\ Ground\ Effect = 0.26461341$	
		$Clean = 0.195534557$	
		$Approach\ , Gear\ Down = 0.123533646$	
		$Landing, Flaps\ , Gear\ Down = 0.250384141$	

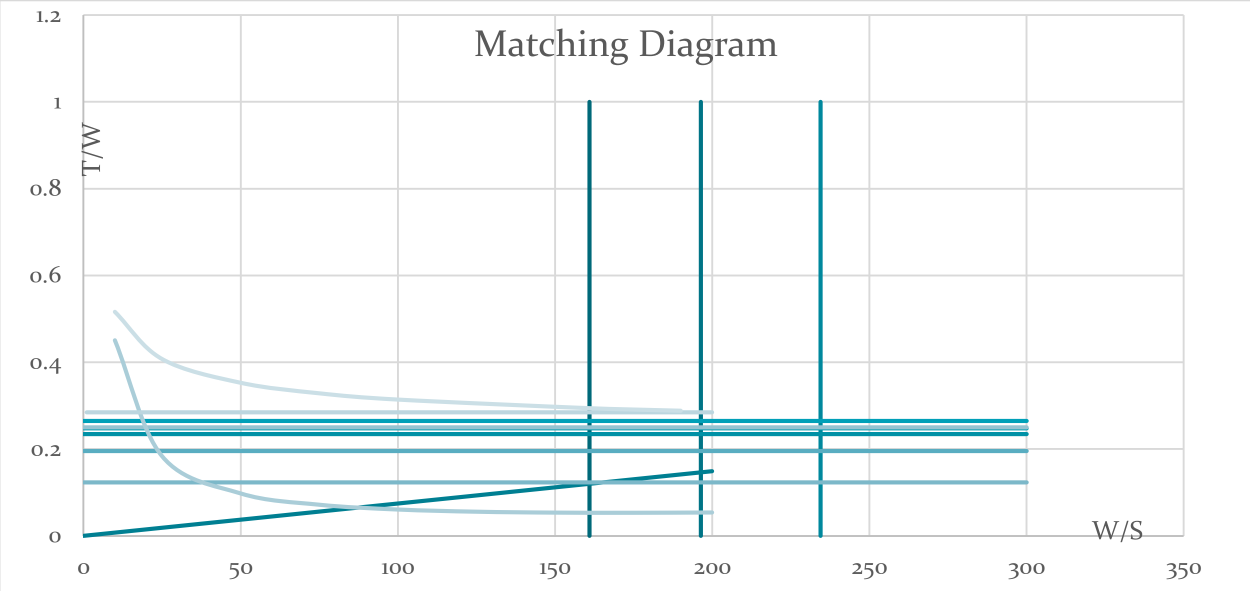
Maneuver Sizing	
$\frac{T}{W}$	$C_{l_{Max_{Cr}}} = 2$
	$\delta_{at\ 35000\ ft} = 0.235374149$
	$M = 0.84$
	$V_{Cr} = 482.27\ {}^{ft}/_{S}$
	$\bar{q} = 244.4859095$
	$\rho_{35000ft} = 0.000738$
	$e = 0.85$

Cruise Sizing	
$\frac{T}{W}$	$C_{D_0} = 0.018356153$
	$\rho_{at\ 35000\ ft} = 0.000738$
	$V_{Cr} = 482.27\ {}^{ft}/_{S}$
	$\bar{q} = 244.4859095$
	$\frac{T}{W} = \frac{W}{S}\left[\left(\bar{q}C_{D_0} + \frac{1}{\left({}^{W}/_{S}\right)^2}\right) + \frac{1}{{}^{1}/_{K}\,\bar{q}}\right]$

Direct Climb Sizing	
Ceiling	
$\frac{T}{W}$	$C_{D_0} = 0.018356153$
	$\frac{L}{D} = 19.73$
	$W_{T.O} = 762725lb$
	$ROC = 8.333333$
	$\rho_{at\ 35000\ ft} = 0.000738$
	$\frac{T}{W} = 0.2845379995652174$
	$W_{T.O} = 762725lb$
	$\rho_{at\ 5594\ ft} = 0.001777700453$
	$H_{Cr} = 35000\ ft$
	$H_{abs} = 46000\ ft$
	$ROC)_0 = 54.84526807$
$\frac{T}{W}$	$\frac{T}{W} = \frac{ROC\left(\rho(C_{D_0}\frac{1}{K})^{\frac{1}{2}}\right)^{\frac{1}{2}}}{\sqrt{2\left(\frac{W}{S}\right)}} + \frac{1}{\frac{L}{D}\Big)_{Max}}$
	$\frac{L}{D}\Big)_{Max} = 18.89224421$
	$AR = 9.813606827$
	$e = 0.85$
	$\rho_{at\ 5594\ ft} = 0.001777700453$
	$K = \frac{1}{\pi e AR}$
	$C_{D_0} = 0.018356153$

13-Matching Diagram

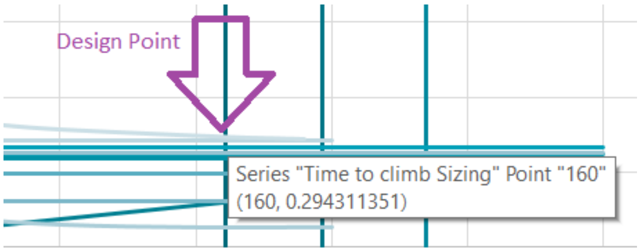
It's time to get what we want! Matching Diagram is all we wanted from the first place. With graphing all the sizing's, we have reached till now in one coordinate we can draw matching diagram, so:



In order to find the design area, take a look at this table, the philosophy of this table is that, a part of every sizing chart has best efficiency in designing, it has lower costs and better fulfilling every needs of the mission than the other parts of chart, so we gathered around all of them to choose the best area for design point.

Sizing Configuration.	Acceptable Zone of The Curve
Stall Speed	Left
Take-off Distance	Above
Landing Distance	Left
Climb	Above
Cruise Speed	Above
Maneuver	Above
Ceiling	Above
Time to Climb	Above

Now we have to locate the design point, a point from the design area which has the maximum of W/S and the minimum of T/W.



14-Part II

This section is all about putting the previous data's together, we now have to engineer every part of the aircraft, have in mind that you can use the peer aircrafts data.

14.1-Selection of the Overall Configuration

Body conceptual design must be met in the following three aspects:

1- The length

2- Width

3- Distance and type of seats

Body length to diameter ratio $\frac{l_f}{d_f}$:

The bigger is the $\frac{l_f}{d_f}$,the body is longer, thus increasing this parameter would make difficulties in take-off Phase for rotation, and with a perfect arc in the bottom of the body we can overcome this problem.

This ratio determines the diameter of the body and determine the number and location of fixed equipment inside the aircraft.

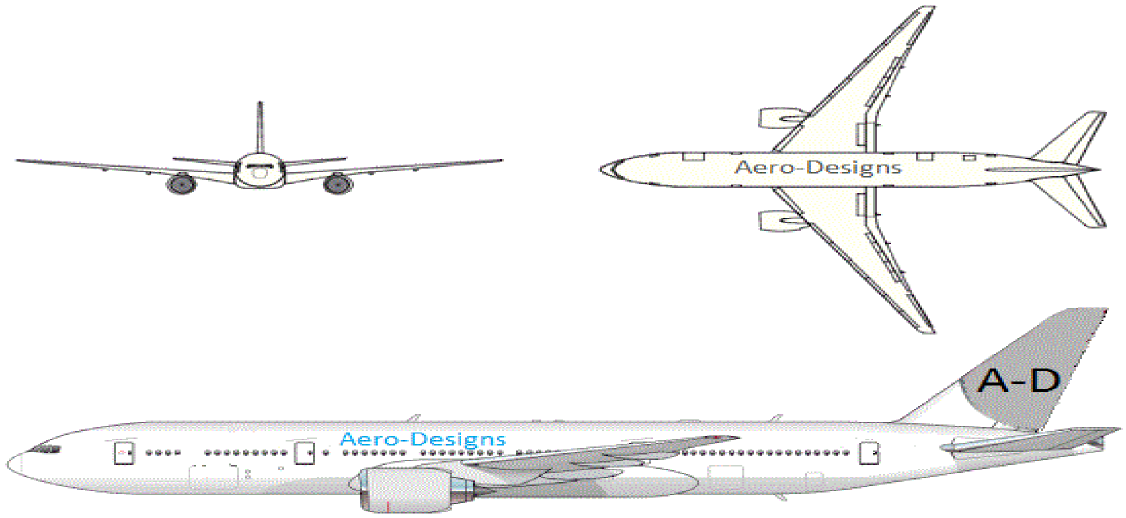
Distances and the number of seats available on aircraft and other fixed equipment's determined by peer aircrafts.

Depending on the arrangement of the seats we determine the width of the body then having $\frac{l_f}{d_f}$ we determine the length of the aircraft.

Airplane type	l_f/d_f
Boeing777-300ER	12.8887
Boeing 747-8	12.4461
Boeing 777-200LR	10.8614

14.2-Dimentional Sketch

The second step in the field of aircraft design, set three overall view planes with foreign size of it, this amounts obtained due to the target aircraft and of course peer aircrafts.



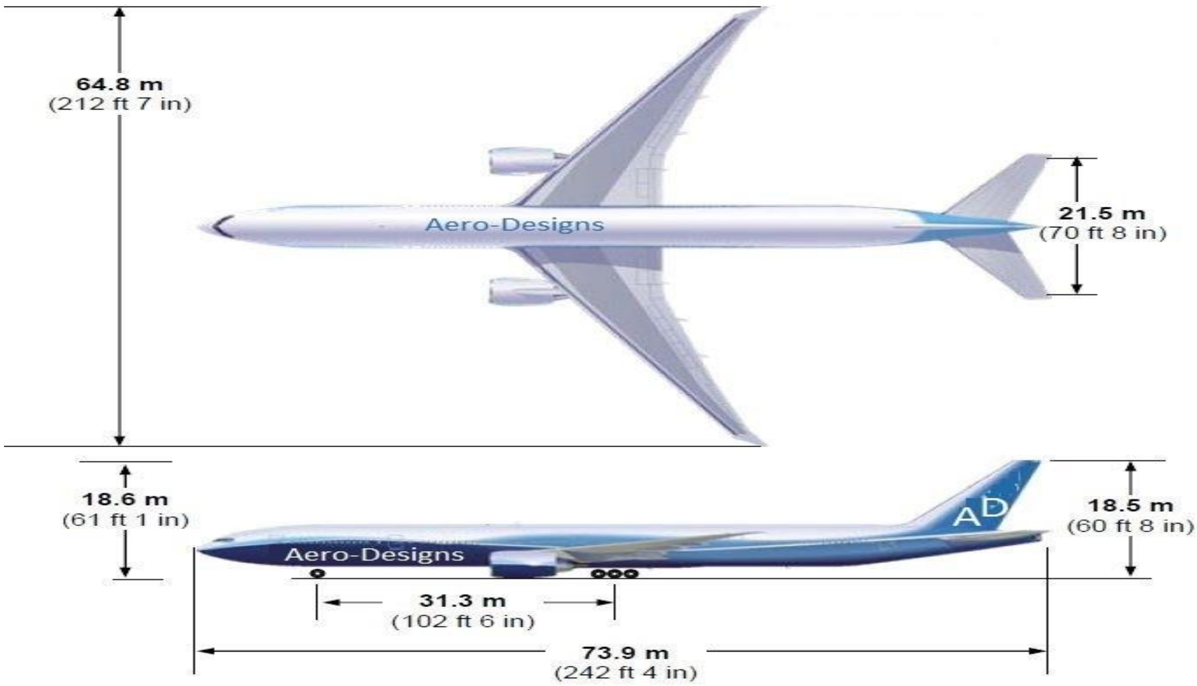


Figure 10 Dimensional Sketch

14.3-Design of Cockpit and Fuselage Layouts:

Cabin Cross section two issues to be considered in the design:

1- Getting on and off from airplane for passengers.

2- There are no specific standards on airplane seats.

Finally, we've reached these sizes from target airplane:

Cabin Width: 19.23 ft

Fuselage Diameter: 20.31 ft

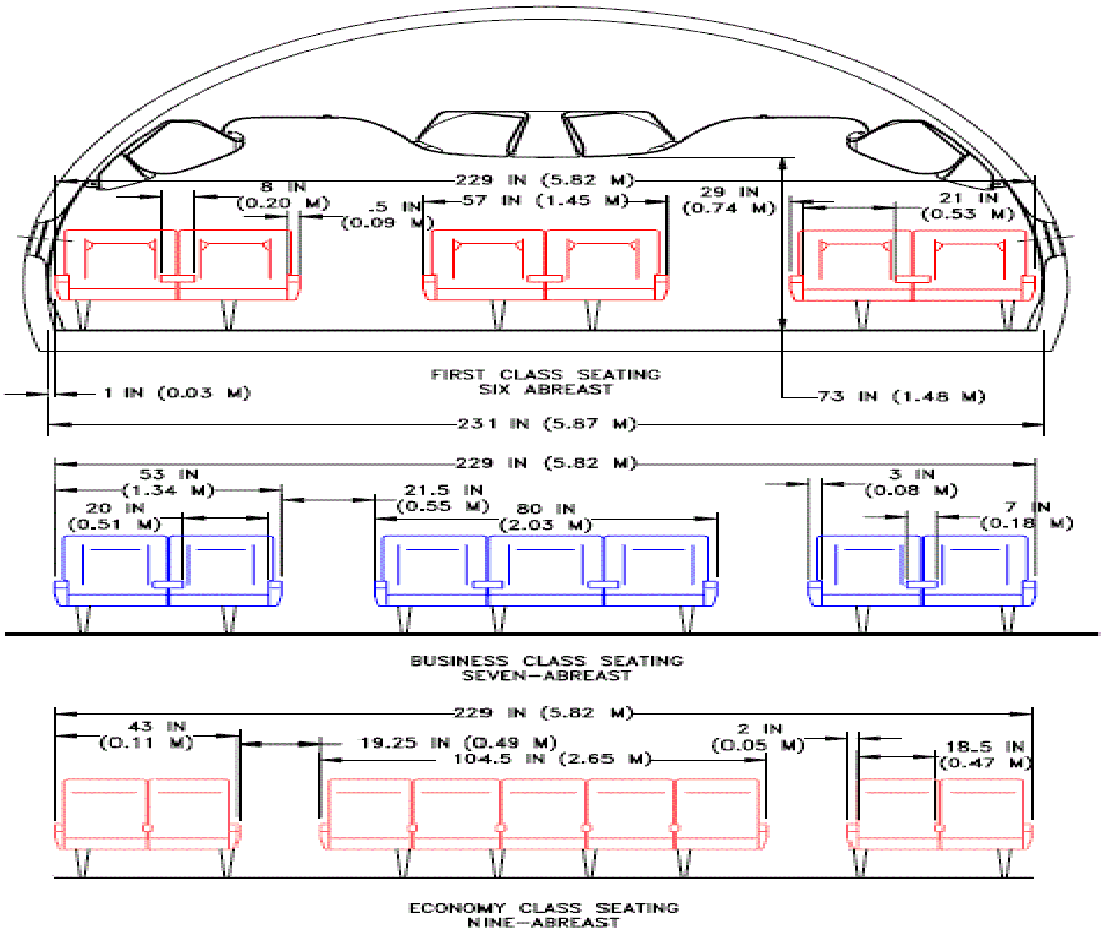


Figure 11 Cabin Cross Section

14.4-Selection & Integration of the Propulsion System:

Usually, aircraft engines are designed according to the ceiling of the flight. Important parameters in this section include:

- Engine Type
- Engine number
- Installation and placement of the engine
- type and number of engines is defined in the mission.
- to determine the location of the engine it is important for the intake of the engine to have the best performance by not breathing any turbulent air.

To select the engine thrust required by the aircraft, we use the matching diagram and the following formula:

$$T_{av} = {}^{T}/_{W} \times W_{TO} = 0.294311351 \times 762725 = 224478.6252\ lbf$$

Then for Safety Factor:

$$S.F = \frac{T_{Req}}{T_{av}}$$

$$T_{Req} = 1.1 \times 224478.6252 = 246926.4847\ lbf$$

This number is divided by the number of engines which stated in the mission (2*Turbofan Engines):

$$T_{Req} = 123463.2439 lbf\ For\ Each\ Engine$$

After a review of our knowledge and view of corporate catalogs engines such as Pratt & Whitney, Rolls Royce, General Electric, came to the conclusion that GE has the most powerful turbofan engine made, that is GE90-115B model. In the following part, statistics of this engine will be mentioned.

Dimensions:

Overall Length	(286,67 inches)
Overall width	(148.38 inches)
Overall Height	(154.56 inches)

Dry Weight: 8761.1 kg (19315 lb.).

Ratings:

Rating	GE90-115B
Thrust, kN (lb)	513,947 (115,540)
	489,304 (110,000)
Flat rating ambient temperature, °C (°F)	30 (86)
	25 (77)

The location of the twin-turbofan engines is under the wing of the aircraft due to Peers and the target aircraft.

14.5-Airfoil Selection for Wing & Tail:

In the design and selection of wings must first define the following parameters for the wings, we have some of these parameters using data to target aircraft:

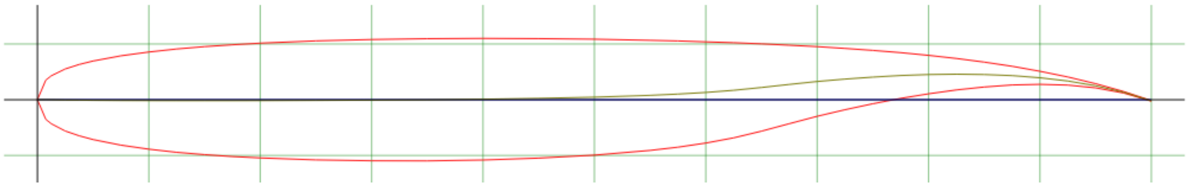
- Wing Area
- Wing Location
- Wing Section (Airfoil)
- Aspect Ratio (AR)
- Taper Ratio (λ)
- Thickness Ratio (t/c)
- Sweep Angle (Λ)
- Dihedral Angle (Γ_w)
- Incidence Angle (i_w)

- Twist Angle (ε_w)
- Wing Tip
- Fuel Volume

Wing Area	4605 ft^2
Wing Location	Low Wing
Wing Section (Airfoil)	Whitcomb-il
Aspect Ratio (AR)	9.813606827
Taper Ratio (λ)	0.29
Thickness Ratio ($^t/_c$)	11% at 35% chord
Sweep Angle (Λ)	31.64°
Dihedral Angle (Γ_w)	5°
Twist Angle (ε_w)	1.5°
Wing Tip	Winglet
Fuel Volume	181283 L

Root & Tip Airfoil Selection:

WHITCOMB INTEGRAL SUPERCRITICAL AIRFOIL (Whitcomb-il)



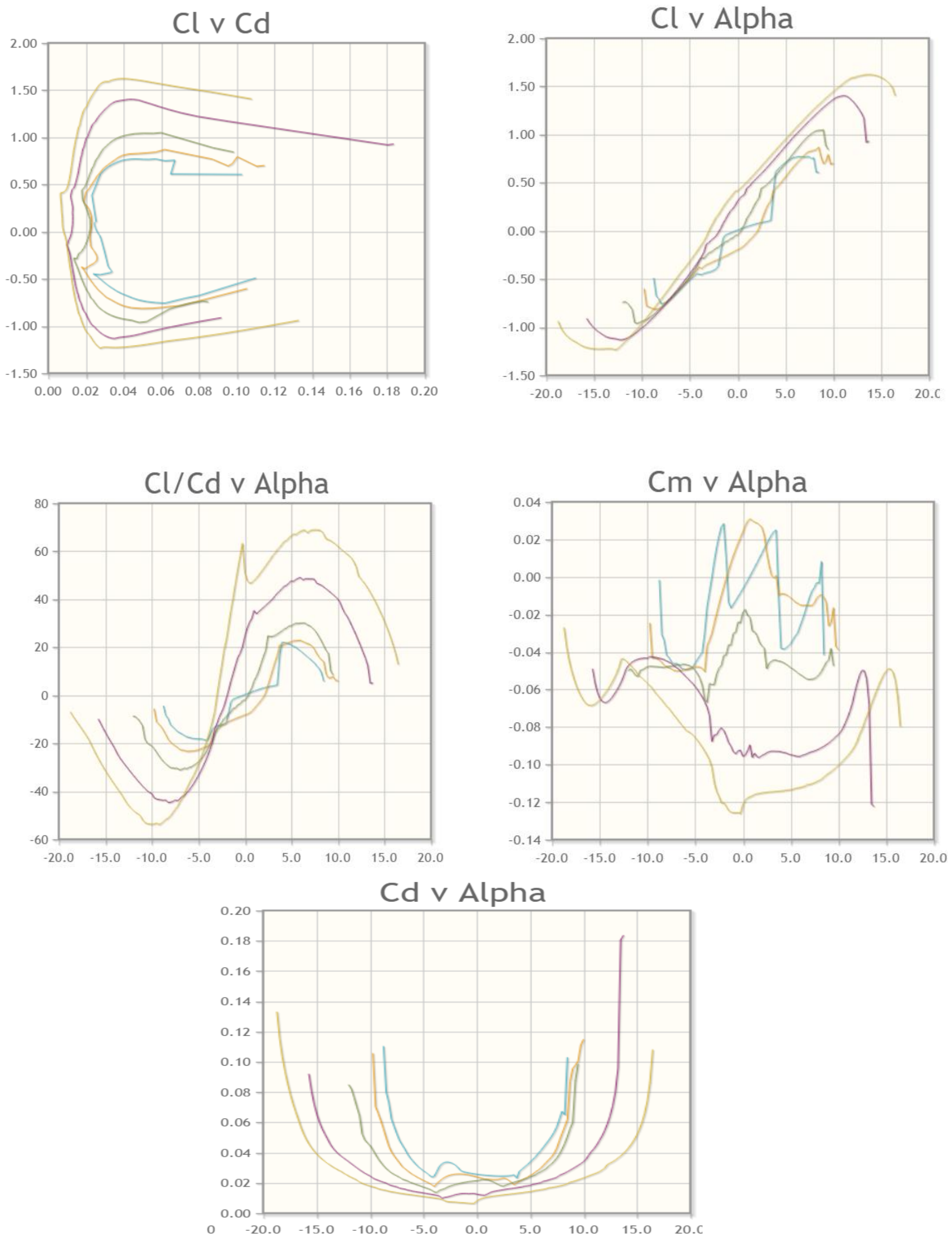


Figure 12 Airfoil Behavior Graph

Tail Airfoil:

1. NACA 0008il

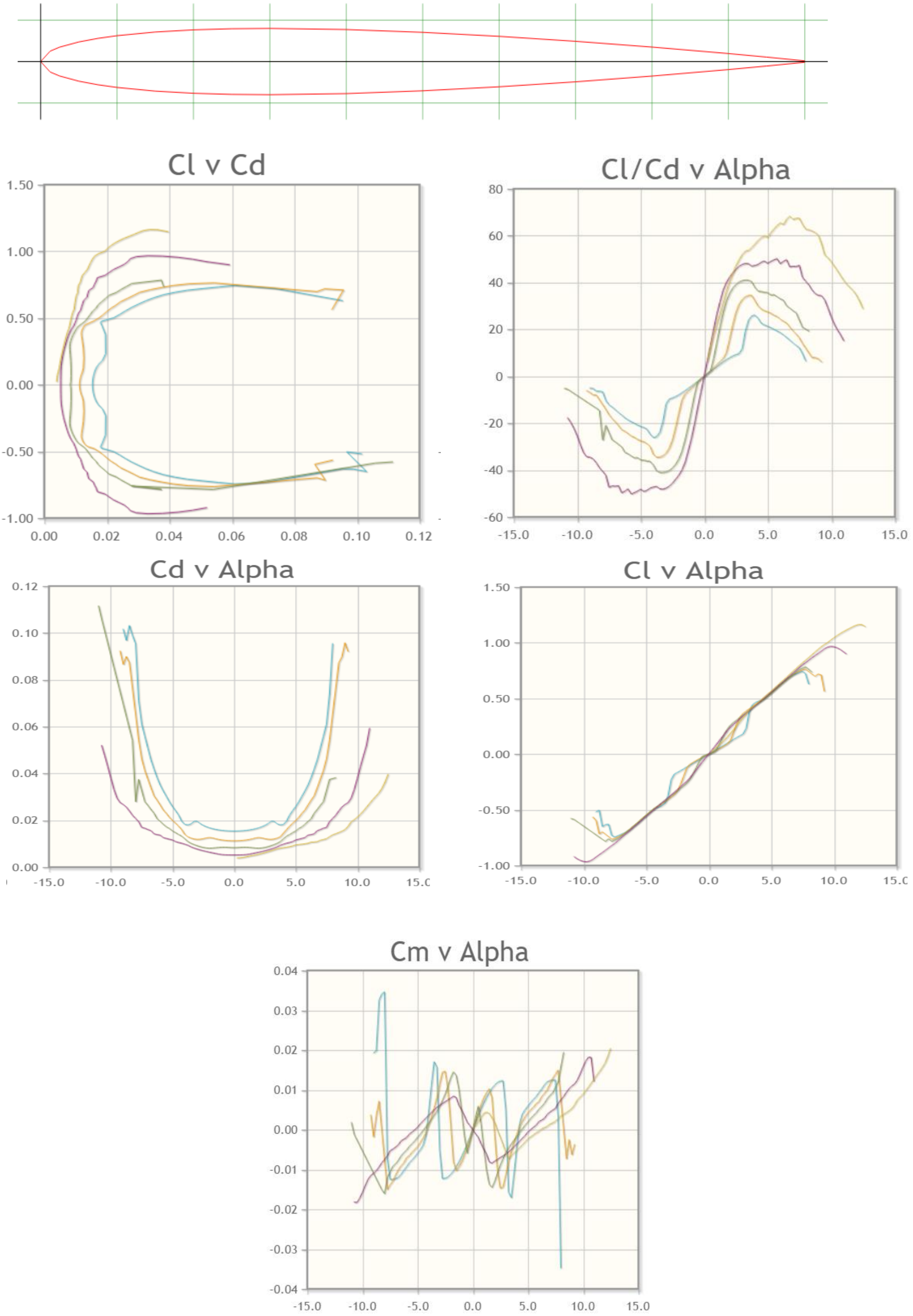


Figure 13 NACA 0008il Behavior

2.NACA 0012H

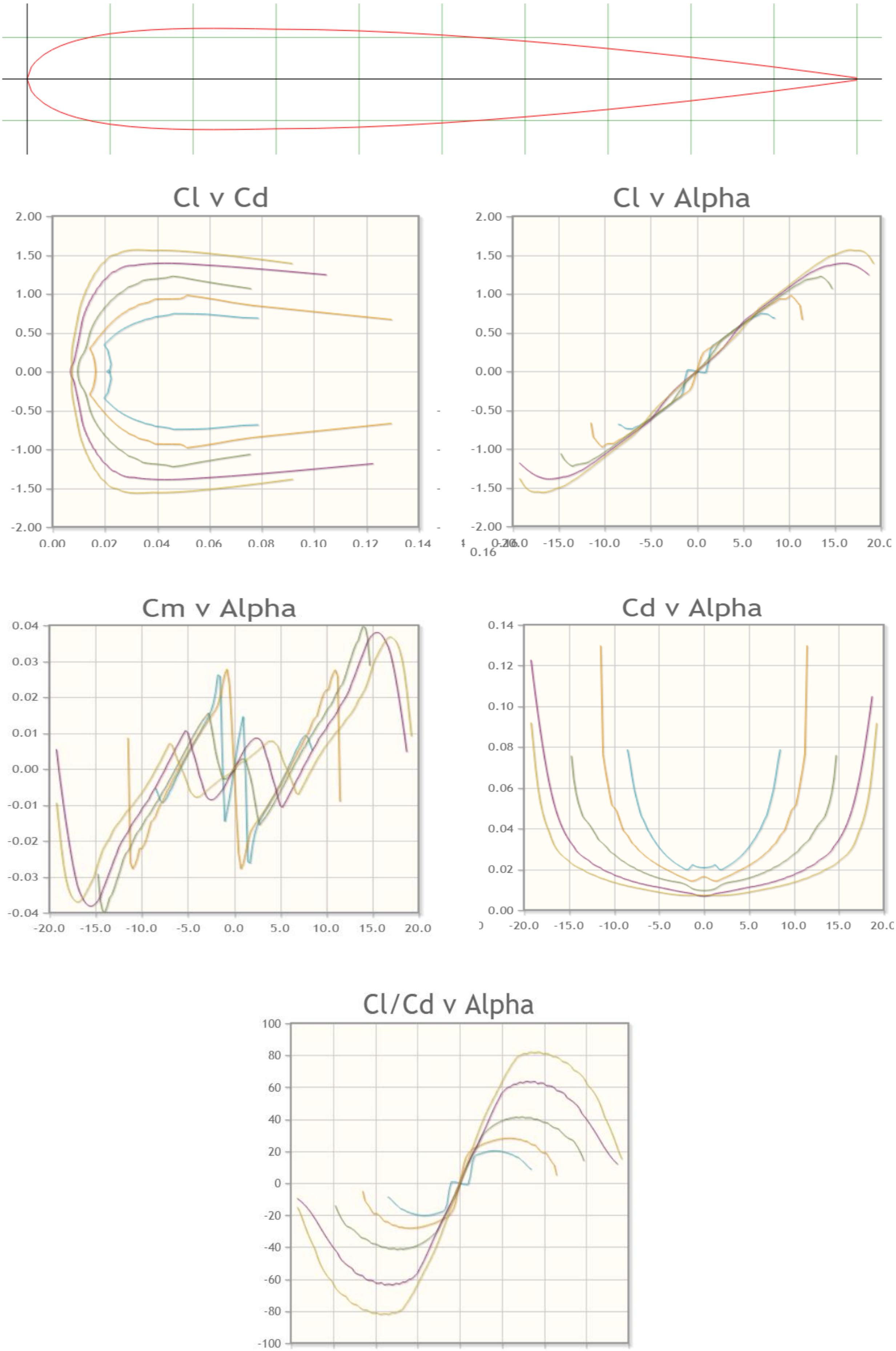


Figure 14 NACA 0012H Behavior

14.7-Empennage Sizing & Disposition & For Control Surface Sizing:

One of the most important tasks of the tail is to stable and trim the aircraft, the longitudinal trim is on the Elevator who is installed on the horizontal tail, and transverse-direction trim is on the Rudder who is installed one the vertical tail.

The tail comes in many forms, each designed to be used in certain aircraft. Using the peer aircrafts tail and especially the target aircraft, and the simplicity of the design and weighing less of the conventional tails, we select this type of tail. The area of vertical and horizontal tail, estimated by the peers and the target aircraft.

Then, to estimate the area of control surfaces on the tail, we refer to Tables 8.7a and 8.7b in Roskam book and read data Se/Sh and Sr/S and Sa/S for peer aircrafts, then interpolate these values and calculate for your plane.

14.8-Class I Method for Landing Gear Sizing & Disposition:

The only points that are raised in landing gear design are:

- How to connect (installed)
- Retractable landing gear

With respect to these points we choose.

Because of the popularity of the nose gear landings, whom have the same size of wheels that makes airplane to be horizontally on the bond, we use this type of landing gear, and it also makes the aircraft more stable on the ground and enhances pilot's view.

And now a bit closer look to our landing gear:


Aero-Designs

15-Summerized Table

MISSION SPECIFICATIONS	
NUMBER OF PASSENGERS	400
WEIGHT OF EACH PASSENGER	175 lbs
BAGGAGE OF EACH PASSENGER	60 lbs
PAYLOAD WEIGHT	94000 lbs
NUMBER OF CREWS	10 lbs
WEIGHT OF EACH CREW	175 lbs
BAGGAGE OF EACH CREW	30 lbs
CREW WEIGHT	2050 lbs
CRUISE RANGE	6500 nm
LOITER TIME	0.75 hours
FLY TO ALTERNATE RANGE	300 nm
CRUISE ALTITUDE	35000 ft
CLIMB TIME	20 min
CRUISE SPEED	0.84 M
CRUISE SPEED	813.9097 fps
CRUISE SPEED	482.27 Knots
T.O FIELD LENGTH	10500 ft
T.O FIELD ALTITUDE	5594 ft
T.O FIELD TEMPERATURE	310.9278 Kelvin
LANDING FIELD LENGTH	8000 ft
LANDING FIELD ALTITUDE	5594 ft
LANDING FIELD TEMPERATURE	310.9278 Kelvin
POWER PLANTS TYPE	Turbofan Engine
NUMBER OF ENGINES	2
PRESSURIZATION	6000 ft.
CERTIFICATION	FAR 25
MISSION FUEL FRACTION ESTIMATION	
Cj)CRUISE	0.46
Cj)LOITER	0.6
Cj)ALTERNATE	0.9
(L/D)CRUISE	17.08
(L/D)LOITER	19.73

(L/D)ALTERNATE	11.835
A	0.15
B	1.056
W T.O	762725
MISSION FUEL FRACTION ESTIMATION 2	
START WEIGHT FRACTION	0.99
TAXI WEIGHT FRACTION	0.99
T.O WEIGHT FRACTION	0.995
CLIMB WEIGHT FRACTION	0.98
CRUISE WEIGHT FRACTION	0.7
LOITER WEIGHT FRACTION	0.997
DESCENT WEIGHT FRACTION	0.99
ALTERNATE WEIGHT FRACTION	0.913
LANDING WEIGHT FRACTION	0.992
Mff	0.586
W F	394710.2lbs
W T.O	762725lbs
W E	268150.6lbs
C	0.581
D	96050
F	3723087.874
Wto/Wpl	6.663887799
Wto/We	3.00367631
Wto/R)Cruise	207.9136511
Wto/E)Loiter	113221.1214
Wto/V)Cruise	-2754.171483
Wto/Cj)Cruise	2887509.306
Wto/(L/D)]Cruise	-77766.64408
Wto/Cj)Loiter	141526.4017
Wto/(L/D))Loiter	-4303.894628
Wto/R)Alternate	1132.498213
Wto/Cj)Alternate	377499.04042
Wto/V)Alternate	-1358.997855
Wto/(L/D)]Alternate	-28707.17903

LANDING DISTANCE SIZING	
WI/WT.O	0.713232161
DRAG POLAR ESTIMATION	
A	-2.5229
B	1.00
C	0.0199
D	0.7531
Cf	0.003
CRUISE SPEED SIZING	
CRUISE ALT DENSITY	0.000738 slug/ft^3
THRUST AT ALT TO S.L THRUST RATIO	0.44086329522875
DIRECT CLIMB SIZING	
RC0	3290.7169842ft/min
TIME TO CLIMB SIZING	
h_abs	46000Ft
***GAMMA**	Less than 15 degree
TARGET AIRPLANE DESIGN POINT	
T/W	0.29754838
W/S	168.295
SIMILAR AIRPLANE DESIGN POINT (Boeing 777-300)	
T/W	0.27878787
W/S	143.322
DESIGN POINT	
T/W	0.294311351
W/S	160
OUTPUT TABLE	
T.O THRUST	224478.6252
Part II	
Overall Configuration	Conventional
$\frac{l_f}{d_f}$	12.8887
Legroom	31 in
Cabin Width	19.23fts
Fuselage Length	242.33333
Fuselage Diameter	20.31fts

Seat Pitch	First Class:22 sits, 61 in pitch Business Class:70 sits, 39 in pitch Economy Class:273 sits,32 in pitch
Aisle Width	First Class:20 in Business Class:17 in Economy Class:17.5 in
Propulsion Type	Turbofan Engine
Maximum Sea level Thrust	115540lbs
Propulsion Manufacturer	General Electrics
Propulsion System Integration	Wing Mounted
Propulsion Unit Cost	U.S $27.5 M for each engine
Wing Sweep	31.64°
Wing Twist	Quantity
Wing Dihedral	Quantity
Wingspan	212.58333ft
Wing Area	4605 ft^2
Aspect Ratio	9.813606827
MAC=8.75m	ZFW:30.2% T.O W:27.4% L.W:30.2%
Root Airfoil	Whitcomb-il
Tip Airfoil	Whitcomb-il
Control Surface Sizing(Sa/Sw)	2.758
Winglet	Yes
Wing Position	Low
Clmax Clean	2
Clmaxt.o	2.4
Flap Type	Single Slotted Three Settings
Clmax Landing	2.8
Clmax Approach	3.0
Tail Configuration	Conventional
Vertical Tail Area	52.3 m^2
Horizontal Tail Area	101.26 m^2

<table>
<tr><td colspan="2">Vertical Tail Airfoil</td><td colspan="2">NACA0008</td></tr>
<tr><td colspan="2">Horizontal Tail Airfoil</td><td colspan="2">NACA0012</td></tr>
<tr><td colspan="2">Vertical Tail control Surface Sizing (Srud/SV)</td><td colspan="2">0.35</td></tr>
<tr><td colspan="2">Horizontal Tail control Surface Sizing (Selevator/Sh)</td><td colspan="2">0.23</td></tr>
<tr><td colspan="2">Landing Gear Type</td><td colspan="2">Retractable tricycle with two main gear and single steerable nose gear</td></tr>
<tr><td colspan="4">AERODYNAMIC PROPERTIES</td></tr>
<tr><td>CONFIGURATION</td><td>e</td><td>DELTA Cd CONF</td><td>Vs knots</td></tr>
<tr><td>CLEAN</td><td>0.85</td><td>0</td><td>170</td></tr>
<tr><td>T.O</td><td>0.85</td><td>0.012</td><td>170</td></tr>
<tr><td>LAND</td><td>0.85</td><td>0.073</td><td>175.6820922</td></tr>
<tr><td>APPROACH</td><td>0.85</td><td>0.0505</td><td>170</td></tr>
<tr><td>GEARS</td><td>0.85</td><td>0.015</td><td>170</td></tr>
<tr><td>CRUISE</td><td>0.85</td><td>0</td><td>170</td></tr>
</table>

- All the calculations and conclusions has gathered in the above tables.
- All the numbers have been engineered and they are also open to new changes if necessary.

16-Sources

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[i] Represented to Prof. Farshad Pazooki

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