Estimation of Optimal Flight Altitude for Reduction in Fuel Consumption by An Aircraft Engine

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***Abstract*— In this paper, the focus is on increasing the efficiency of the aircraft by increasing the propulsive efficiency of its engine. As we go higher in altitude, there is a change in pressure, temperature, density etc. Hence we shall estimate an altitude where the engine is most efficient by considering all the above given parameters. For this we select various cities of India above which flights transits every day at a particular altitude. For these places we try to use upper air observations (like soundings). The mean of the data which were collected for over 10 years is given as input to MATLAB coding which will simulate Turbofan engine analysis. Output from this MATLAB coding will give us specific fuel consumption (S.F.C) at various altitudes; using this plot we will try to understand how the change in inlet condition affects the efficiency of turbofan cycle. At the end of this paper we will also try to analyze the effect of change of oxygen concentration in burning efficiency and we will find the optimal flight altitude at least over two cities of India.**

Index Terms—Propulsive efficiency, flight transit, reduction in fuel consumption,optimal flight altitude, turbofan engine, specific fuel consumption.

I. INTRODUCTION

As we move higher in altitude we see a drastic change in the temperature and pressure. In the lower regions of atmosphere (up to 12 Kms) the temperature drops uniformly with change in altitude. This is because the atmosphere is warmed by convected heat from the earth's surface and as we move higher temperature reduces. Pressure also drops uniformly as we move higher in altitude it can vary from 101.325 Kpa at sea level to 26.5Kpa at 10Km altitude. Commercial aircraft generally flies up to 13 Kms and as there is change in ambient conditions from ground to higher altitudes the inlet condition for aircraft's engine changes.

Here by applying the variation in the inlet condition we try to study the change. For this a MATLAB coding for turbojet cycle analyses was written and data from various sounding observations was given as input. Generally a sounding observation will contain pressure, temperature, relative humidity, wind speed and wind direction data up to an altitude of 30 to 35 kms. From which we selected temperature and pressure data as input parameters (ambient parameters) for turbojet cycle analysis and relative humidity to calculate the local mach number.
The engine performance may be described in several ways. One of the useful parameters is specific fuel consumption, or S.F.C. For turbojets and fans, the S.F.C is usually expressed as the thrust specific fuel consumption or T.S.F.C. It is defined as the weight of the fuel burned per unit time, per unit thrust.

In order to find the optimal flight altitude we select Chennai and Delhi and data for 10 years was collected for the same month (for Chennai February month was selected and for Delhi we select two months June and December). The mean of this data from past 10 years was given as input to MATLAB turbofan cycle analyses coding and specific fuel consumption (S.F.C) was obtained as a result. The graphs between altitude and Specific fuel consumption (SFC) were plotted.

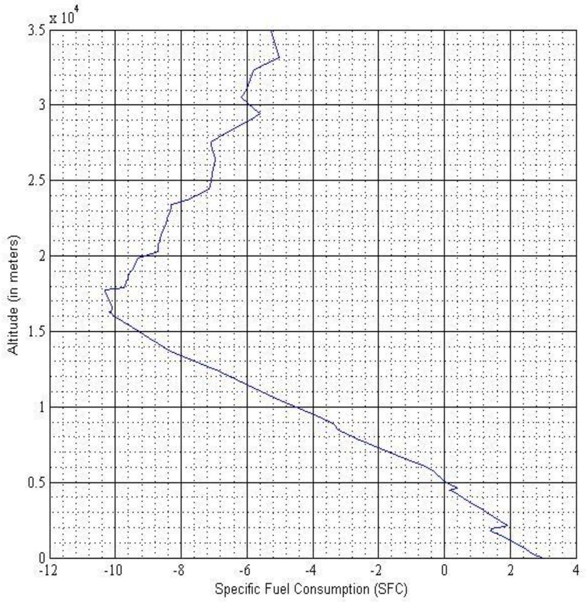

Figure-1: Altitude versus Specific fuel consumption (SFC) over Chennai in month of February

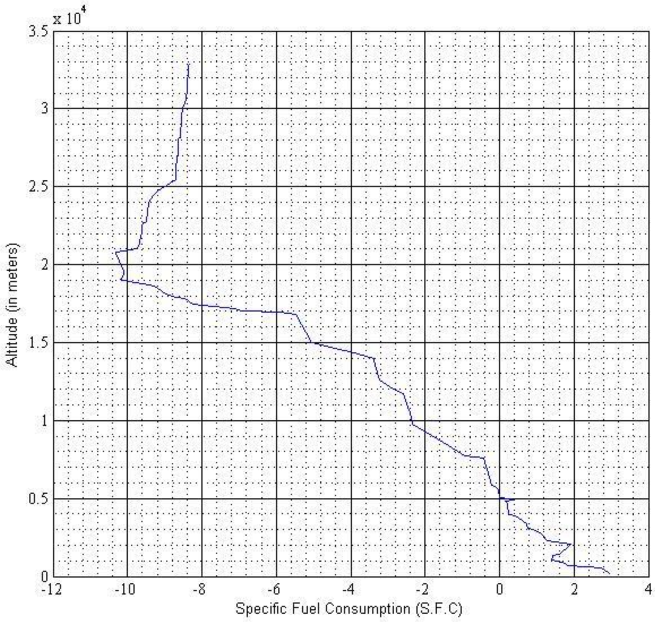

Figure-2: Altitude versus Specific fuel consumption (SFC) over Delhi in month of June

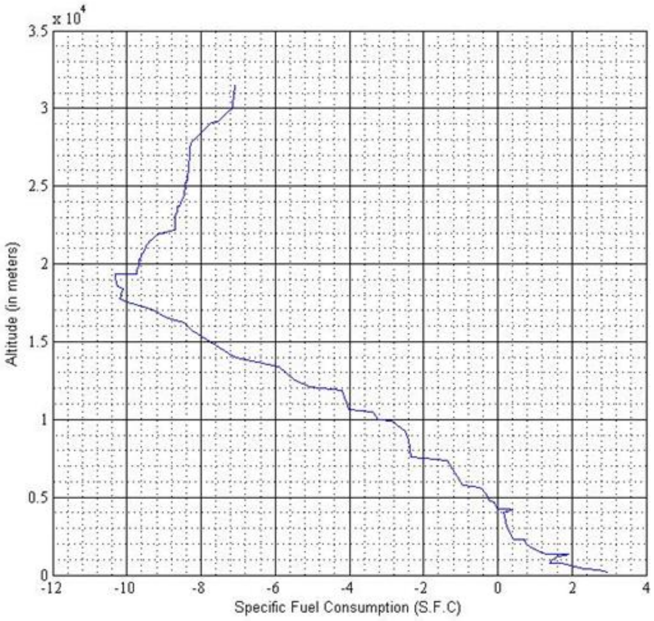

Figure-3: Altitude versus Specific fuel consumption (SFC) over Delhi in month of December

As we can see that the SFC continuously reduces with increase in altitude, this indicates that as higher we go the efficiency of turbojet engine should increase. Moreover over Delhi we can observe some shift in lowest SFC point as we move from June to December, this change is understood to occur due to change from summer session to winter session.

Although from the above observations we found that as we move higher and higher in altitude the efficiency of an aircraft's engine should increase but in real condition this is not the case as with increase in altitude there is change in oxygen concentration also. As all the aircrafts engines are air breathing (i.e. they need air from atmosphere for combustion and propulsion) so the concentration of oxygen matters a lot, if the oxygen concentration is less than required the combustion would be incomplete and there would be great drop in thrust generated by engines.

Oxygen concentration will vary as we move higher in altitude; this change can vary from place to place. We here took a common oxygen concentration change as data for each state of India was not available. The following graph was plotted for oxygen percentage versus altitude.

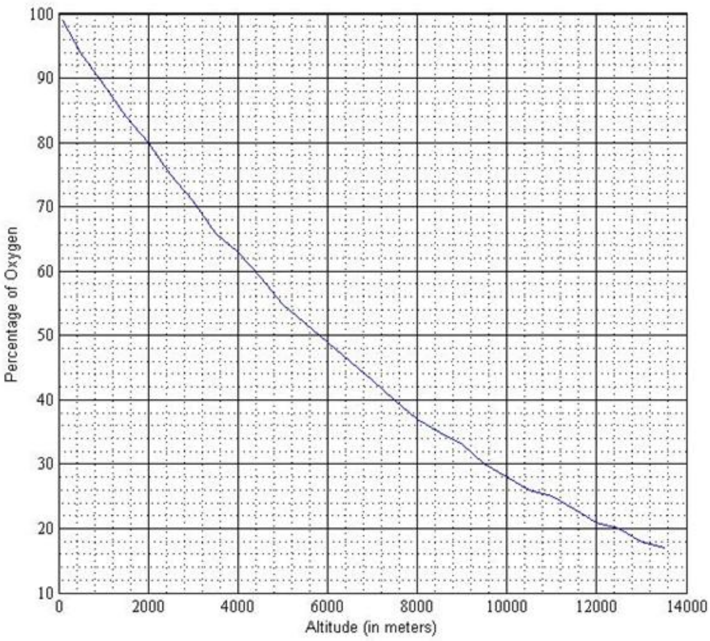

Figure-4: Altitude versus percentage of oxygen

Here in above graph the oxygen concentration at 0 meters of altitude is 100%, this means that 100% of its concentration at sea level (i.e. at 0 meter oxygen percentage is 100% of 21%, whereas at 13500 meters oxygen percentage is just 17% of 21%).

As discussed earlier if the drop in oxygen concentration is greater, in this case it is possible that engine may not get sufficient oxygen in order to burn the fuels completely resulting in sudden drop in engine thrust.

This suggests that oxygen concentration would be applying a limiting condition on altitude beyond which the efficiency would again drop drastically. Now we focus on finding that limit after which efficiency of engine will drop. For this we select an aircraft AIRBUS A320 with engine V-2500-A1 which is a twin spool subsonic turbo fan engine with pressure ratio of 29.4 and bypass ratio of 5.42, air mass flow rate through this engine is 305Kg/s.

Jet fuel is a specific blend of fuels used in aviation to run turbine powered engines. The most common commercial Jet fuel is Jet A and Jet A-1 which is a cheaper and less refined version of the Jet fuel blend. These jet fuels can be combinations of Unleaded kerosene (Jet A), Naptha-kerosene (Jet B), Anti-Freeze, Hydrocarbons, Antioxidants, Metal deactivators, N-heptane, Isooctane. As the composition of a jet fuel is kept secret hence we will consider only pure kerosene based fuel, like Dodecane also known as dihexyl, bihexyl, adakane 12 or duodecane. Molecular formula for dodecane is $CH_3(CH_2)_{10}CH_3$ (or $C_{12}H_{26}$).

Now as this fuel is burned in presence of oxygen, so we have to calculate minimum amount of oxygen required by the engine to burn fuel completely. This is done as follows:

1) Fuel consumption for AIRBUS A320 with engine V-2500-A1 was found to be 2450Kg/h or 0.681 Kg/sec.
2) Number of moles of fuel that was entering combustion chamber per second was calculated to 4 moles/ second (molar mass of dodecane, $C_{12}H_{26}$ is 170).
3) Now from the following equation,

$$C_{12}H_{26}(l) + 18.5\ O_2(g) \rightarrow 12\ CO_2(g) + 13\ H_2O(g)$$

   We find number of moles of oxygen required per second for complete combustion, which is 74 moles/ second.
4) Oxygen consumed per second is 2.368Kg/ second (this is minimum amount of oxygen required for complete combustion of fuel).

As we go up in higher altitude air becomes thinner and hence oxygen concentration is reduced. Here we try to find the amount of air mass flow rate (per second) in order to get 2.368 kg of oxygen per second in combustion chamber. This is done as follows:
The average molar mass of air is = 29g/ mol
Molar mass of oxygen is = 32g/mol
(At sea level)
There is 21% of oxygen in air by volume,
The volume of air is 100/21 =4.76 times of O_2
1 volume of oxygen is in 4.76 volumes air

From Avagardo:
1 mol of oxygen is in 4.76 mol of air
32 gram of oxygen is in 4.76*29= 138gram of air
2368 gram of oxygen is in (2368/32)*138= 10212 gram of air.

This means for complete combustion air entering combustion chamber should be 10.212kg/ second. (For sea level)
Similarly, weight of air that should enter combustion chamber for complete combustion of fuel was estimated for difference altitude and is listed as follows:

Table-1: Minimum air mass flow rate (per second) for different altitudes

Altitude (meters)	Mass of air per second (kg/sec)	Altitude (meters)	Mass of air per second (Kg/sec)
0	10.212	7500	25.472
100	10.238	8000	27.616
500	10.864	8500	29.184
1000	11.504	9000	30.96
1500	12.160	9500	34.048
2000	12.768	10000	36.992
2500	13.616	10500	39.296
3000	14.384	11000	40.864
3500	15.483	11500	44.416
4000	16.208	12000	48.656
4500	17.328	12500	51.088
5000	18.576	13000	56.768
5500	19.648	13500	60.112
6000	20.848	14000	63.856
6500	22.208	14500	68.128
7000	23.760	15000	78.608

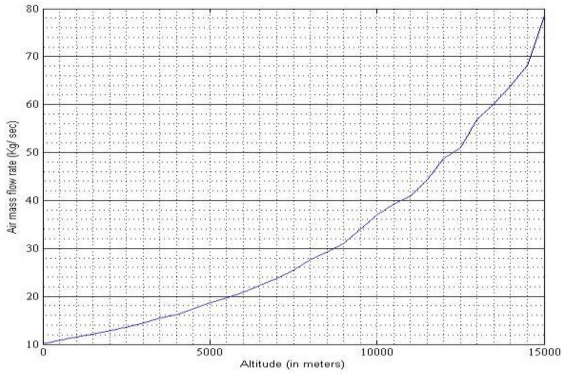

Fig-5: Minimum air mass flow rate (per second) for different altitudes

For our aircraft AIRBUS A320 with engine V-2500-A1 which is a twin spool subsonic turbo fan engine with pressure ratio of 29.4 and bypass ratio of 5.42, air mass flow rate through this engine is 305Kg/s.

Mass flow rate that will bypass the main engine is 257.492 Kg/s and mass flow rate that will reach combustion chamber is 47.507 Kg/s. So if the minimum required air mass flow rate exceeds this limit there will be a drop in efficiency and thrust of the engine. Now for optimal flight altitude where efficiency of engines tends to be maximum it will lie close to this point.

From the table-1 we can see closest point to this limit lies somewhere between 11500 meters to 12000 meters.

CONCLUSION

Plotting the optimal altitude over graphs we get

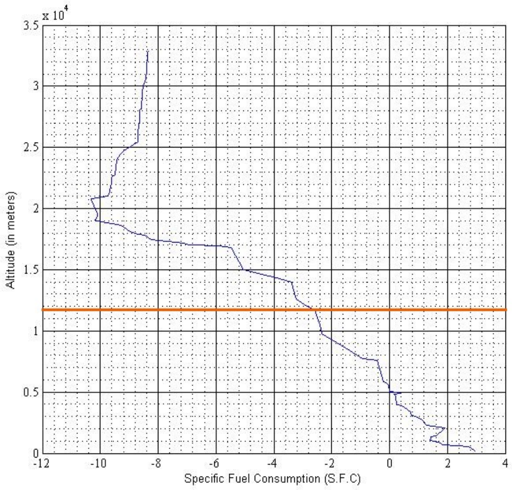

Fig-6: Optimal flight altitude over SFC versus Altitude plot (Chennai February

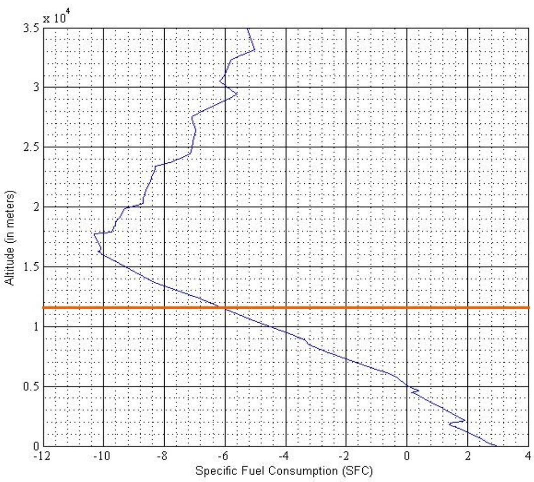

Fig-7: Optimal flight altitude over SFC versus Altitude plot (Delhi June)

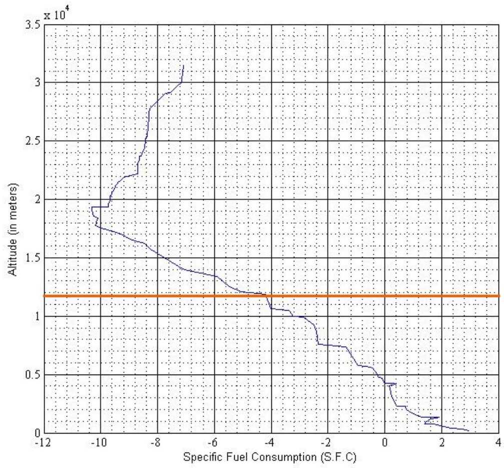

Fig-8: Optimal flight altitude over SFC versus Altitude plot (Delhi December)

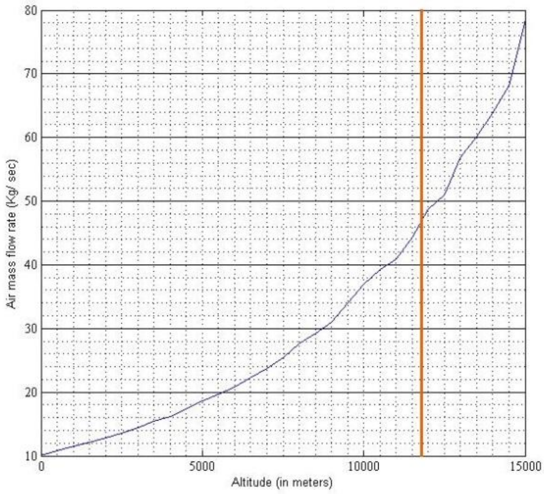

Fig-9: Minimum air mass flow rate (per second) for different altitudes with optimal flight altitude

From the above final graphs we can conclude that when a flight flies in optimal flight altitude over Chennai in February its specific fuel consumption (S.F.C) is around -6 but when the same flight flies over Delhi in the same optimal flight altitude its specific fuel consumption (S.F.C) is around -2.5 in June and around -4.25 in December.

We also have to understand that this optimal flight altitude will change with every aircraft and engine. Also to make it more accurate we will have to conduct experiments in order to know the exact concentration of oxygen profile over the city/ state.

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