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“Mathematical research regarding the effect of Carbon Dioxide polluted environment on Thrust of an Airbus A380”

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ABSTRACT: AIRBUS A380 is the largest passenger aircraft operating in the present era. It uses 4 “Rolls-Royce Trent 900”, two on each wings. In this era of mankind, pollution level and greenhouse effect has stolen the limelight. It is not only becoming a threat to the environment but also on the aviation sector too. It is obvious that the air-breathing engine will not be taking in the normal air and will breathe a carbon-rich air in the upcoming future. As a result, the Thrust and Thrust Specific Fuel Consumption (TSFC) will differ from the present data. I have shown mathematically the difference it can have.

KEYWORDS: Specific Heat, Thrust, Thrust Specific Fuel Consumption

I. INTRODUCTION

Thrust tells the propelling force of an aircraft. It is calculated using Momentum Principle of Newton’s 2nd Law. It consists of Momentum Thrust and Pressure Thrust. Since A380 is the largest passenger airline having enormous weight, the thrust will be greatest compared to other aircraft. Thrust Specific Fuel Consumption (TSFC) is the amount of fuel consumed per unit thrust produced.

II. METHODS

I have particularly chosen model A380 to calculate the Thrust and TSFC. Various engine data is obtained from web. It was seen from weather data that on March in the year 2020, carbon dioxide content and temperature at ambient condition was the highest this year. March temperature recorded to be the 3rd warmest in last 60 years [1]. Here I will be using Specific heat of Carbon-Dioxide instead of pure air. I have made an assumption that the atmospheric level is containing abundant carbon dioxide because of increased in pollution. Thus there is a rise in ambient temperature instead of 288K. I have neglected the amount of pressure thrust and considered majorly of the momentum thrust. The various mathematical calculations have been carried out following the pattern by IIT Bombay i.e. Indian Institute of Technology, Bombay [2].

III. ENGINE DATA

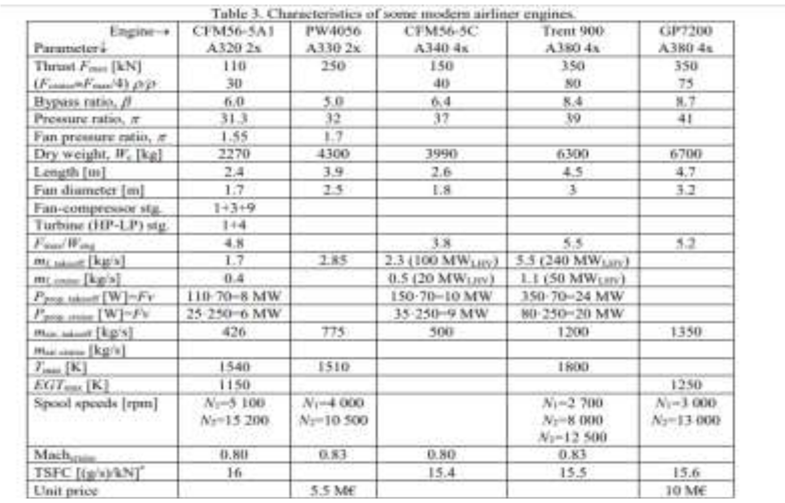

Table 3. Characteristics of some modern airliner engines.

Engine→ Parameter↓	CFM56-5A1 A320 2x	PW4056 A330 2x	CFM56-5C A340 4x	Trent 900 A380 4x	GP7200 A380 4x
Thrust F_{max} [kN]	110	250	150	350	350
(F_{cruise}≈F_{max}/4) ρ/ρ_0	30		40	80	75
Bypass ratio, β	6.0	5.0	6.4	8.4	8.7
Pressure ratio, π	31.3	32	37	39	41
Fan pressure ratio, π	1.55	1.7			
Dry weight, W_e [kg]	2270	4300	3990	6300	6700
Length [m]	2.4	3.9	2.6	4.5	4.7
Fan diameter [m]	1.7	2.5	1.8	3	3.2
Fan-compressor stg.	1+3+9				
Turbine (HP-LP) stg.	1+4				
F_{max}/W_{eng}	4.8		3.8	5.5	5.2
$m_{f,takeoff}$ [kg/s]	1.7	2.85	2.3 (100 MW_{LHV})	5.5 (240 MW_{LHV})	
$m_{f,cruise}$ [kg/s]	0.4		0.5 (20 MW_{LHV})	1.1 (50 MW_{LHV})	
$P_{prop,takeoff}$ [W]=Fv	110·70=8 MW		150·70=10 MW	350·70=24 MW	
$P_{prop,cruise}$ [W]=Fv	25·250=6 MW		35·250=9 MW	80·250=20 MW	
$m_{air,takeoff}$ [kg/s]	426	775	500	1200	1350
$m_{air,cruise}$ [kg/s]					
T_{max} [K]	1540	1510		1800	
EGT_{max} [K]	1150				1250
Spool speeds [rpm]	N_1=5 100 N_2=15 200	N_1=4 000 N_2=10 500		N_1=2 700 N_2=8 000 N_3=12 500	N_1=3 000 N_2=13 000
$Mach_{cruise}$	0.80	0.83	0.80	0.83	
TSFC [(g/s)/kN]*	16		15.4	15.5	15.6
Unit price		5.5 M€			10 M€

Table 1: Rolls-Royce Trent 900 A380 Data [3]

Month	Forecast CO_2
January	413.4
February	414.0
March	414.9
April	416.8
May	417.4
June	416.7
July	414.7
August	412.6
September	411.0
October	411.5
November	413.3
December	414.7

Table2: Monthly Carbon Dioxide forecast in the year 2020 by Mauna Loa forecast [4]

Mach number of A380 (M) = 0.85 [5]
Speed of Aircraft (V) = 634 mph = 283.423m/sec (maximum speed recorded till date) [5]
Concentration of carbon dioxide in March, 2020 = 414.9 ppm [4]
Surface temperature in March, 2020 (T_a) = 26℃ = (26 + 273.15) K = 299.15K [6]
Cv (Specific heat at constant volume) of Carbon Dioxide at 299.15K = 0.655 (KJ/kg-K) [7]
Cp(Specific heat at constant pressure) of Carbon Dioxide at 299.15 K = 0.846 (KJ/kg–K) [8]
Specific heat ratio of CO_2 (γ) = 0.846/0.655 = 1.29
Ambient pressure in March, 2020 (P_a) = 1.013 bar
Fan pressure ratio (π_f) = 1.55 [3]
Overall pressure ratio (π) = 39 [3]
Bypass ratio (β) = 8.4 [3]
Turbine Inlet temperature (T_{04}) = 1800K [3]
Air mass flow = 1200 kg/sec [3]
Heat of reaction of the fuel: 43 MJ/kg
R = Cp – Cv = 1.846 – 0.655 = 1191 J/kg-K

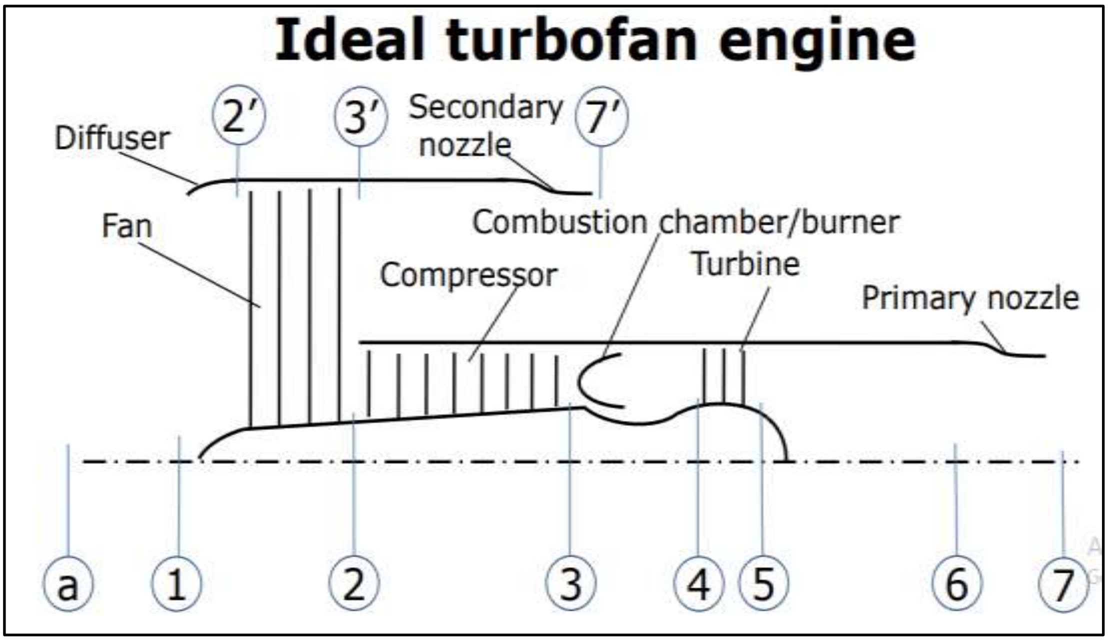

Figure 2: Schematic representation of a Turbofan engine [2]

IV. CALCULATIONS

4.1 INTAKECALCULATIONS (1-2'):

Using isentropic relation of Temperature-Mach at the intake,

$$\bullet \frac{T_{02'}}{T_a} = (1+\frac{\gamma-1}{2}M^2) = (1+\frac{1.29-1}{2}0.85^2) = 1.1047$$

$$\Rightarrow T_{02'} = (1.1047*T_a) = (1.1047*2.9915) = 330.48K$$

Using Pressure-Temperature isentropic relation,

$$\bullet \frac{P_{02'}}{P_a} = (\frac{T_{02'}}{T_a})^{\frac{\gamma}{\gamma-1}} = (1.1047)^{\frac{1.29}{1.29-1}} = (1.1047)^{4.44} = 1.56$$

$$\Rightarrow P_{02'} = (1.56*P_a) = 1.56*1.013 = 1.58bar$$

4.2 CALCULATION OF FAN (2' – 3'):

Fan pressure ratio,

$$\bullet \pi_f = \frac{P_{03'}}{P_{02'}} = 1.55$$

$$\Rightarrow P_{03'} = (1.55*P_{02'}) = (1.55*1.58) = 2.44bar$$

$$\bullet \frac{T_{03'}}{T_{02'}} = (\frac{P_{03'}}{P_{02'}})^{\frac{\gamma-1}{\gamma}} = (\frac{2.44}{1.58})^{\frac{1.29-1}{1.29}} = (1.54)^{0.22} = 1.102$$

$$\Rightarrow T_{03'} = 1.102*T_{02'} = 1.102*330.48 = 364.19K$$

4.3 CALCULATION OF COMPRESSOR (2 – 3):

Compressor pressure ratio,

$$\bullet \pi_c = {}^{\pi}\!/_{1.65} = {}^{39}\!/_{1.65} = 23.63$$

$$\bullet \frac{P_{03}}{P_{02}} = \pi_c = 23.63$$

$$\Rightarrow P_{03} = \pi_c * P_{02} = 23.63*2.44 = 57.67bar$$

$$\bullet \frac{T_{03}}{T_{02}} = (\frac{P_{03}}{p_{02}})^{\frac{\gamma-1}{\gamma}} = (23.63)^{0.224} = 2.03$$

$$\Rightarrow T_{03} = 2.03*T_{02} = (2.03*364.19)K = 741.46K$$

4.4 CALCULATION OF COMBUSTION CHAMBER (3 – 4):

Fuel-air ratio,

$$\bullet f = \frac{(\frac{T_{04}}{T_{03}})-1}{(\frac{Q_R}{Cp_{CO2}*T_{03}})-\frac{T_{04}}{T_{03}}} = \frac{(\frac{1800}{741.46})-1}{(\frac{43*10^6}{0.846*10^3*741.46})-\frac{1800}{741.46}} = 0.0216$$

4.5 CALCULATION OF HIGH-PRESSURE TURBINE (4 – 5'):

Using principle of conservation of energy principle,

• $\dot{m}_{aH}\, Cp(T_{03}-T_{02}) = \dot{m}_{t}\, Cp(T_{04}-T_{05'})$

$$\Rightarrow T_{05'} = T_{04} - \frac{(T_{03}-T_{02})}{(1+f)}$$

$$\Rightarrow T_{05'} = 1800 - \frac{(741.46-364.19)}{(1+0.0216)}$$

$$\Rightarrow T_{05'} = 1800 - 369.29$$

$$\Rightarrow T_{05'} = 1430.70K$$

• $\dfrac{P_{05'}}{P_{04}} = (\dfrac{T_{05'}}{T_{04}})^{\frac{\gamma}{\gamma-1}} = (\dfrac{1430.70}{1800})^{\frac{1.29}{1.29-1}} = (0.79)^{4.44} = 0.35$

$$\Rightarrow P_{05'} = 0.35 * P_{04} = 0.35 * 57.67 = 20.21bar$$

4.6 CALCULATION OF LOW-PRESSURE TURBINE (5' – 5):

Using principle of conservation of energy principle,

• $\dot{m}_{aC}\, Cp(T_{03'}-T_{02'}) = \dot{m}_{t}\, Cp(T_{05'}-T_{05})$

$$\Rightarrow T_{05} = T_{05'} - \beta(\frac{T_{03'}-T_{02'}}{1+f})$$

$$\Rightarrow T_{05} = 1430.70 - 8.4(\frac{364.19-330.48}{1+0.0216})$$

$$\Rightarrow T_{05} = 1430.70 - 8.4(32.99)$$

$$\Rightarrow T_{05} = 1153.52K$$

• $\dfrac{P_{05}}{P_{05'}} = (\dfrac{T_{05}}{T_{05'}})^{\frac{\gamma}{\gamma-1}} = (\dfrac{1153.52}{1430.70})^{\frac{1.29}{1.29-1}} = (0.806)^{4.44} = 0.383$

$$\Rightarrow P_{05} = 0.383 * P_{05'} = 0.383 * 20.21 = 7.74bar$$

4.7 CALCULATION OF PRIMARY NOZZLE (5 – 7):

Primary Nozzle pressure ratio,

• $\dfrac{P_{05}}{P_{a}} = \dfrac{7.74}{1.013} = 7.64$

Critical pressure ratio,

• $\dfrac{P_{05}}{P^{\otimes}} = (\dfrac{\gamma+1}{2})^{\frac{\gamma}{\gamma-1}} = (\dfrac{1.29+1}{2})^{\frac{1.29}{1.29-1}} = (1.14)^{4.44} = 1.79$

- Therefore the nozzle is choked.
- Temperature and pressure must be calculated with respect to critical properties.

• $T_{7} = T^{\otimes} = T_{05}(\dfrac{2}{\gamma+1}) = 1153.52(\dfrac{2}{1.29+1})$

$$\Rightarrow T_{7} = 1007.44K$$

$$\bullet P_7 = P^{\otimes} = P_{05}\left(\frac{P^{\otimes}}{P_{05}}\right) = 7.74\left(\frac{1}{1.79}\right)$$

$$\Rightarrow P_7 = 4.32 bar$$

Exit velocity at the primary nozzle,

$$\bullet v_{e1} = \sqrt{\gamma R T_7} = \sqrt{1.29 * 1191 * 1007.44} = 1244.11 m/\sec$$

4.8 CALCULATION OF SECONDARY NOZZLE (3' – 7'):

Secondary Nozzle pressure ratio,

$$\bullet \frac{P_{03'}}{P_a} = \frac{2.44}{1.013} = 2.41$$

Critical Pressure ratio,

$$\bullet \frac{P_{03}}{P^{\otimes}} = \left(\frac{\gamma+1}{2}\right)^{\frac{\gamma}{\gamma-1}} = \left(\frac{1.29+1}{2}\right)^{\frac{1.29}{1.29-1}} = 1.83$$

- Therefore the nozzle is choked.
- Temperature and pressure must be calculated with respect to critical properties.

$$\bullet P_{7'} = P^{\otimes} = \frac{P_{03}}{1.83} = \frac{57.67}{1.83} = 31.51 bar$$

$$\bullet T_{7'} = T^{\otimes} = T_{03}\left(\frac{2}{\gamma+1}\right) = \frac{741.46}{1.83} = 405.16 K$$

Exit velocity at Secondary nozzle,

$$\bullet v_{e2} = \sqrt{\gamma R T_{7'}} = \sqrt{1.29 * 1191 * 405.16} = 788.97 m/\sec$$

Bypass ratio,

$$\bullet \beta = \frac{\dot{m}_{aC}}{\dot{m}_{aH}} = 8.4$$

Air mass flow rate,

$$\dot{m}_{aH} + \dot{m}_{aC} = 1200 kg/\sec$$

Mass flow rate of hot air through Combustion chamber,

$$\dot{m}_{aH} = \frac{1200}{9.4} = 127.65 kg/\sec$$

Mass flow rate of cold air through bypass duct,

$$\dot{m}_{aC} = 1200 - 127.66 = 1072.34 kg/\sec$$

Total Thrust produced by both the nozzles,

$$\bullet T = \dot{m}_{aH}[(1+f)v_{e1} - v] + \dot{m}_{aC}(v_{e2} - v)$$

$$\Rightarrow T = \dot{m}_{aH}[(1+f)v_{e1} - v] + \beta \dot{m}_{aH}(v_{e2} - v)$$

$$\Rightarrow T = 127.66[(1+0.0216)1244.11 - 283.423] + 1072.34(788.97 - 283.423)$$

$$\Rightarrow T = 127.66(987.55) + 1072.34(505.55)$$

$$\Rightarrow T = 127.65 kN$$

Mass flow rate of fuel,

$$\dot{m}_f = f * \dot{m}_a = 0.0216 * 1200 = 25.92 kg / \sec$$

Thrust Specific Fuel Consumption (TSFC),

$$\bullet TSFC = \frac{\dot{m}_f}{T} = \frac{25.92}{127.65 * 10^3} = 203.05[(g / \sec) / kN]$$

V. COMPARISON TABLE

Parameters	From Data (Table 1)	My Calculation
1. Thrust	350 kN	127.65 kN
2. TSFC	15.5 [(g/sec)/kN]	203.05 [(g/sec)/kN]

Decrease in Thrust = [(350 – 127.65)] / 350 = 63.52%
Increase in TSFC = [(203.05 – 15.5)] / 203.05 = 92.36%

VI. CONCLUSION

From the table it can be seen that in a carbon dioxide rich environment, the Thrust produced by A380 is decreased by 63.52% and TSFC is increased by 92.36%. We have to keep in mind; this calculation is done keeping in view a carbon-dioxide rich environment although there are other gases in air. It is estimated by forecasting department that carbon-dioxide level in the atmosphere will continue to rise because of industrialisation and global warming will peak. It will impact air travel in the upcoming times as the price of fuel will rise and Thrust to Weight ratio will increase leading to lesser passengers carrying capacity. Economy of airlines will fall to great extent due to fewer passengers. I have made an approximate calculation here although in general it may not be the exact. So we need to decrease carbon emission and take major precautions to decrease global warming and to prevent major effect on airline economy in the future.

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