Analysis Calculation Performance Engine Turbofan CFM56-7B In Aircraft Boeing 737-900ER With Comparison Enginesim Program

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Abstract: The performance of an aircraft engine is important to note, this is certainly related to the main function of the machine as a driving force. Studies parametric cycle calculation based on the basic theory Aero Thermodynamics turbofan engines is one way that can be done to determine peforma an aircraft engine. This paper tries to study or examine the performance calculation for this type of turbofan engine that is associated with the condition of an aircraft flying height and throttle certain settings according to the flying height.
Keywords: turbofan engine, engine performance, airplane engine development

1. Introduction

Machines on an aircraft is one of the main components of great importance. The main function of the machine itself is in addition to a power source, the driving or driving, the engine also needed to be able to meet a variety of energy sources of the entire system in the plane.
Factors that come from outside the engine of which is the condition of the surrounding air (environment) associated with the inlet air conditions, such as flow rate, temperature, density and pressure. While the factors derived from the engine is more likely to be caused by variations in the design and dimensions of the machine, as well as power control (throttle settings) used by pilots.
There are several ways you can do to determine performance an aircraft engine, including through studies calculation of the theoretical thermodynamic cycle or parametric, other than it can also be tested operationally in the laboratory (ground running test cell) or test direct operational aircraft (flight test).

2. Theoretical Basis

Theoretically turbofan engine design is the result of the fusion between design turbojet and turboprop engines, in other words within the scope of operational turbofan engine (turbofan engine envelope) is located on the condition of the scope of operational turbojet engine and turboprop engines.

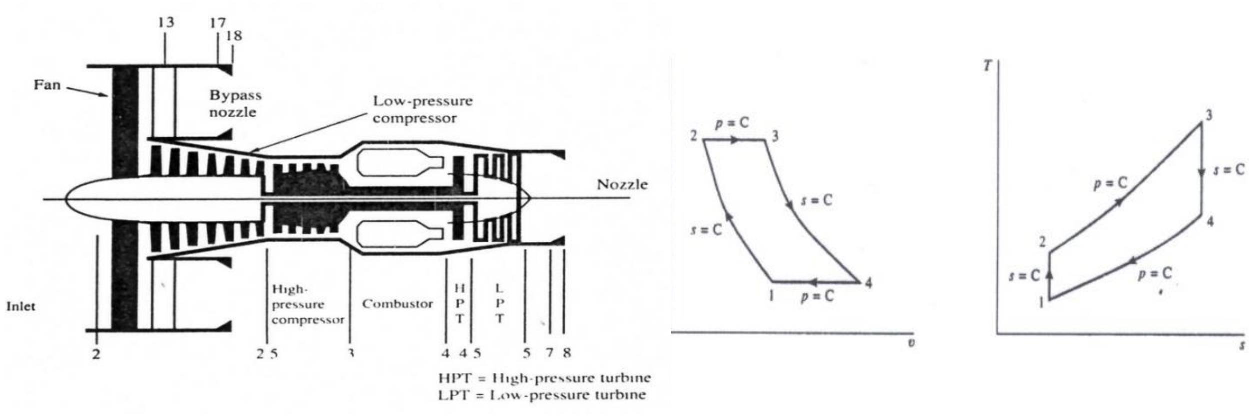


Fig 2.1. Brayton cycle diagram[1)]

3. Program Simulation Enginesim 1.7

In operation simulation program is designed to interact with the changing values of the engine parameters are different, and we can work with this program.

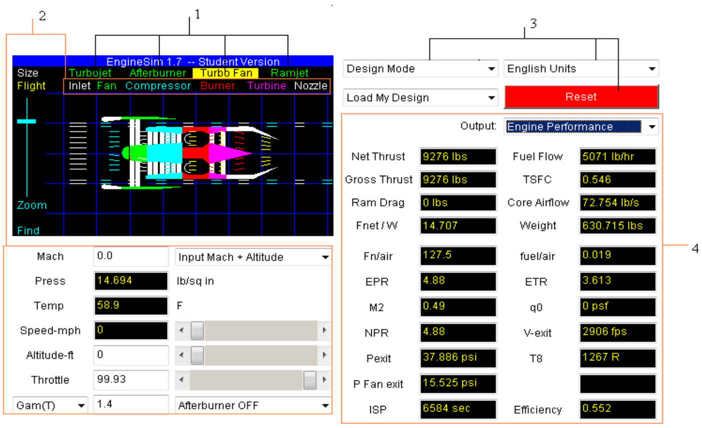


Fig 3.1. EngineSim software Display Program

1) Draft Machinery
2) Selection (Mode, Unit)
3) Material Input
4) Output Display

3.1 Specification Engine CFM56 – 7 On Aircraft Boeing 737-900ER

Type of engine : Turbofan
Arrangement : Two spool axial flow
Rotation : Clockwise (ALF)
Compressors
Fan : Single stage
LP Compressor : Four stages
HP Compressor : Nine stages
Combustion chamber : Annular SAC (option DAC)
Turbines
HP Turbine : Single stage
LP Turbine : Four stages
Overall dimensions
Length 2.51m (98.72 ins)
Height 1.83m (72.00 ins)
Width 2.12m (83.40 ins)
Performance
Take-off thrust (SLS) 19500 - 27300 lbs
Take-off flat rated 86/30
Temperature °F/°C
Max climb thrust 5962 Ibs
By-pass ratio 5.1:1 to 5.5:1
TSFC Max 0,38 lbm/hr/lbf

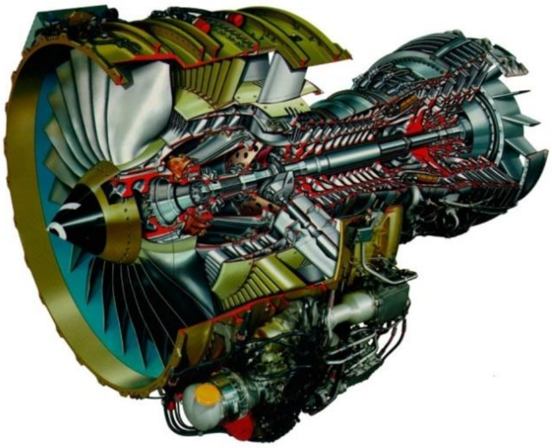


Fig 3.1.1. Engine CFM56 – 7B in aircraft Boeing 737-900ER

4. Calculation And Discussion

Discussion of performance or performance turbofan engines shall be review in flying height and speed for commonly performed to fly cruise (cruise flight) class aircraft Boeing 737 - 900ER this, including air pressure conditions surrounding (ambient water pressure), air density (ambient air density) and air temperature (ambient air temperature)

- γ = 1,4
- c_p = 0,240 Btu/lbm.^{0}R
- h_{PR} = 18400 Btu/lbm
- g_c = 32.174 ft . lbm/(lbf.sec^2)
- *Turbine inlet temperature* (T_{t4}) = 2500 ^{o}R
- *Compresor pressure ratio* (π_c) = 27,8 : 1
- *Fan pressure ratio* (π_f) = 1,7 : 1
- *Bypass ratio* (α) = 5,1 : 1

4.1 Manual Calculation Engine Performance Flying Altitude 25,000 ft

Before the start of a calculation, we can look at data parameters air condition at an altitude flying of 25,000 ft, and a cruising speed of Mach 0.791, namely:
Temperature ambient (T_o) : 429,623 ^{0}R
Pressure ambient - P_o : 786,338 lb/ft^2
Density ambient – ρ : 0,00106 slug/ft^3

a) Values ideal gas constant (R):

$$R = \frac{\gamma - 1}{\gamma} c_p \quad R = \frac{1,4-1}{1,4} \times (0,24 \times 778,16) = 53,359 \text{ lbf.ft/lbm.}^0\text{R}$$

b) The next step, sonic speed that occurred at an altitude of 25,000 ft

$$a_0 = \sqrt{\gamma \ . \ R \ . \ g_c \ . \ T_0} = \sqrt{1,4 \times 53,359 \times 32,174 \times 429,623} = 1.016,164 \, ft/\sec$$

c) Comparison between total temperature to the temperature of the air static-free, obtained:

$$\tau_r = 1 + \left(\frac{\gamma - 1}{2} \times M_0^2 \right) \quad \tau_r = 1 + \left(\frac{1,4-1}{2} \times 0,791^2 \right) = 1 + 0,125 = 1,125$$

d) Furthermore, we can determine the ratio between the turbine inlet temperature (TIT) with ambient water temperature - To:

$$\tau_\lambda = \frac{T_{t4}}{T_0} \quad \tau_\lambda = \frac{2500}{429{,}623} = 5{,}819$$

e) By knowing the compression ratio of 27.8, the equation that is in can price compressor temperature ratio

$$\tau_c = (\pi_c)^{(\gamma-1)/\gamma} \quad = (27{,}8)^{(1{,}4-1)/1{,}4} = (27{,}8)^{0{,}285} = 2{,}579$$

f) As well as compressor temperature ratio, in recognition of the fan pressure ratio of 1.7, the in the can fan temperature ratio:

$$\tau_f = (\pi_f)^{(\gamma-1)/\gamma} = (1{,}7)^{(1{,}4-1)/1{,}4} = (1{,}7)^{0{,}285} = 1{,}163$$

g) Comparison between mass air flow rate at the speed of sound at the core engine:

$$\frac{V_9}{a_0} = \sqrt{\frac{2}{\gamma-1}\left\{\tau_\lambda - \tau_r\left[\tau_c - 1 + \alpha\left(\tau_f - 1\right)\right] - \frac{\tau_\lambda}{\tau_r\tau_c}\right\}}$$

$$= \sqrt{\frac{2}{1{,}4-1} \times \left\{5{,}819 - 1{,}125\left[2{,}579 - 1 + 5{,}1\left(1{,}163 - 1\right)\right] - \frac{5{,}819}{1{,}125 \times 2{,}579}\right\}} = \sqrt{5{,}515} = 2{,}348$$

h) Comparison of the mass flow rate of air to the fan with the speed of sound

$$\frac{V_{19}}{a_0} = \sqrt{\frac{2}{\gamma-1}\left(\tau_r\tau_f - 1\right)} = \sqrt{\frac{2}{1{,}4-1} \times \left(1{,}125 \times 1{,}163 - 1\right)} = \sqrt{5 \times (0{,}308)}$$

$$= \sqrt{1{,}54} = 1{,}240$$

i) Thrust Specific obtained:

$$\frac{F}{m_0} = \frac{a_0}{g_c}\frac{1}{1+\alpha}\left[\frac{V_9}{a_0} - M_0 + \alpha\left(\frac{V_{19}}{a_0} - M_0\right)\right]$$

$$= \frac{1.016{,}164}{32{,}174} \times \frac{1}{1+5{,}1} \times \left[2{,}348 - 0{,}791 + 5{,}1\left(1{,}240 - 0{,}791\right)\right]$$

$$= 31{,}583 \times 0{,}163 \times 3{,}846 = 19{,}799\, lbf\ / lbm / \sec$$

j) Fuel to Air Ratio (FAR) :

$$f = \frac{c_p T_0}{h_{PR}}\left(\tau_\lambda - \tau_r\tau_c\right)$$

$$= \frac{0{,}240 \times 429{,}623}{18400} \times \left(5{,}819 - 1{,}125 \times 2{,}579\right) = \frac{103{,}1095}{18400} \times \left(5{,}819 - 2{,}901\right)$$

$$= 0{,}005603 \times 2{,}918 = 0{,}0163$$

k) Thrust Specific Fuel Consumption (TSFC) :

$$S = \frac{f}{\left(1+\alpha\right)\left(F/m_0\right)} = \frac{0{,}0163}{\left(1+5{,}1\right) \times \left(19{,}799\right)} = \frac{0{,}0163}{6{,}1 \times 19{,}799} = \frac{0{,}0163}{120{,}773}$$

$$= 1{,}3496 \times 10^{-4}\ \text{lbm/sec/lbf} = 0{,}4858\, lbm/hr/lbf$$

l) *Thrust Ratio* :

$$FR = \frac{V_9/a_0 - M_0}{V_{19}/a_0 - M_0} = \frac{2{,}348 - 0{,}791}{1{,}240 - 0{,}791} = \frac{1{,}557}{0{,}449} = 3{,}467$$

m) *Thermal efficiency (ηT)*

$$\eta_T = \frac{a_0^2\left[(1+f)(V_9/a_0)^2 + \alpha(V_{19}/a_0)^2 - (1+\alpha)M_0^2\right]}{2.g_c.f.h_{PR}} \times 100\%$$

$$\eta_T = \frac{983{,}300^2\left[(1+0{,}0173)(2{,}609)^2 + 5{,}1(1{,}240)^2 - (1+5{,}1)\times 0{,}791^2\right]}{2\times 32{,}174\times 0{,}0173\times 18400\times 778{,}16} \times 100\% = 71{,}87\%$$

n) *Propulsive Efficiency* (η_P):

$$\eta_P = \frac{2M_0\left[(1+f)V_9/a_0 + \alpha(V_{19}/a_0) - (1+\alpha)M_0\right]}{(1+f)(V_9/a_0)^2 + \alpha(V_{19}/a_0)^2 - (1+\alpha)M_0^2} \times 100\%$$

$$\eta_P = \frac{2\times 0{,}791\left[(1+0{,}0173)\times 2{,}609 + 5{,}1(1{,}240) - (1+5{,}1)0{,}791\right]}{(1+0{,}0173)(2{,}609)^2 + 5{,}1(1{,}240)^2 - (1+5{,}1)\times 0{,}791^2} \times 100\%$$

$$= \frac{1{,}582\left[4{,}153\right]}{10{,}955} \times 100\% = 59{,}97\%$$

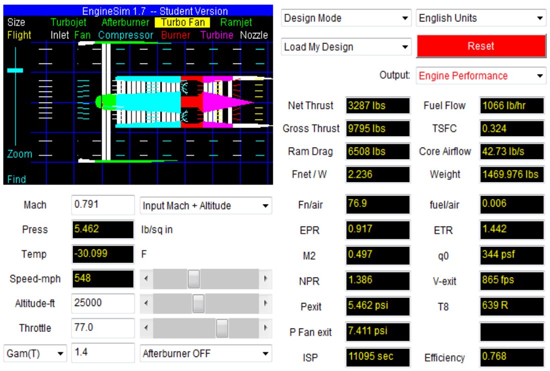
o) *Overall efficiency* (η_0) :

$$\eta_0 = (\eta_T.\eta_P)\times 100\% \quad \eta_0 = (0{,}7187 \times 0{,}5997)\times 100\% = 43{,}10\%$$

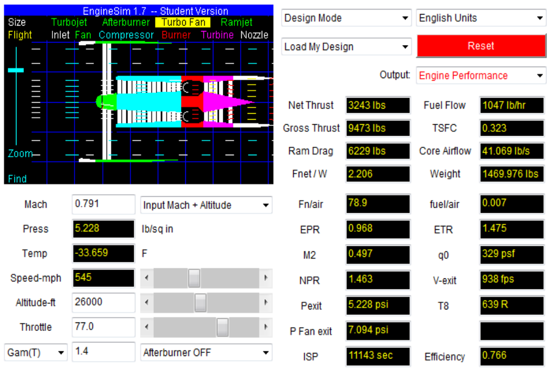
4.2 Calculations Using EngineSim Software Program

In this computational calculation is a calculation that will be used to determine the ratio at any height the throttle 77% and Mach 0791, which is commonly done to fly cruise (cruise flight) class Boeing 737-900ER aircraft is

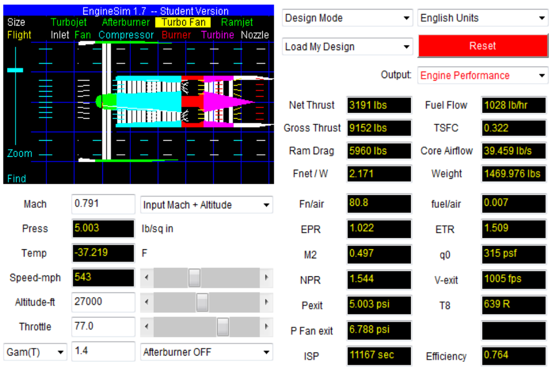
The height of 25,000



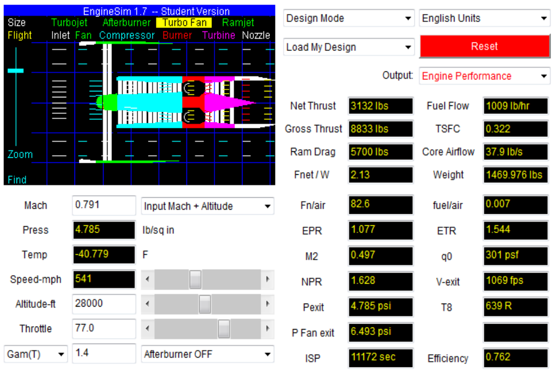
The height of 26,000



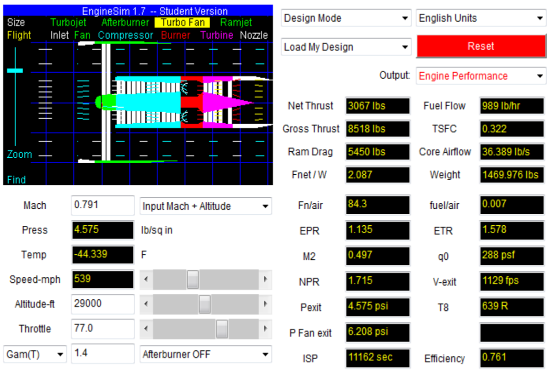
The height of 27,000



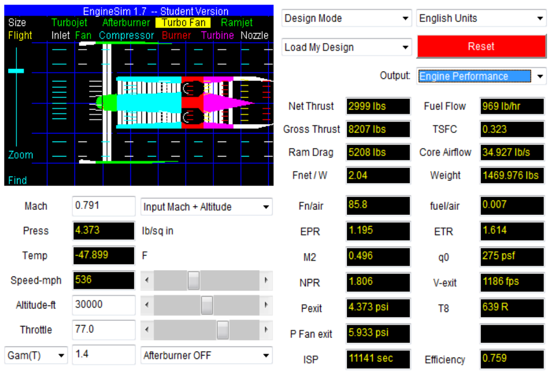
The height of 28,000



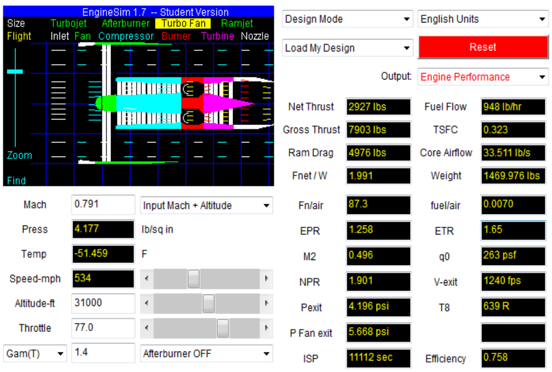
The height of 29,000



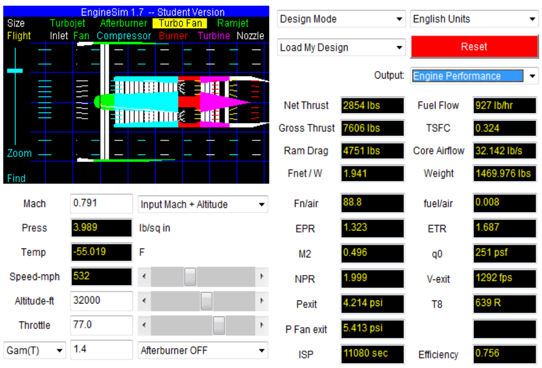
The height of 30,000



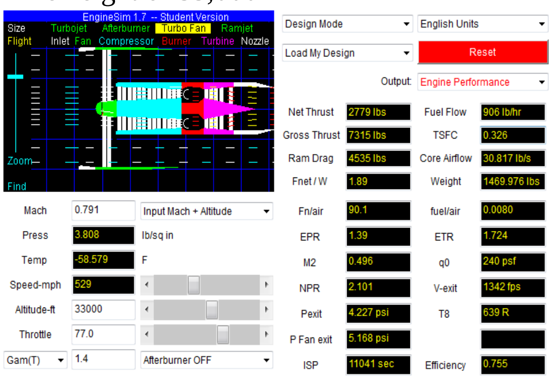
The height of 31,000



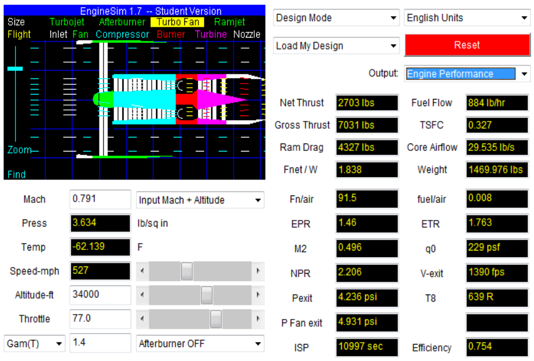
The height of 32,000



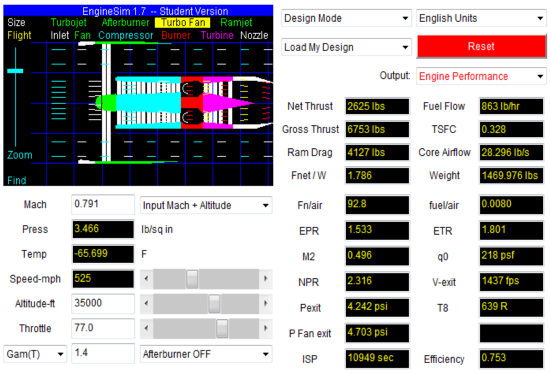
The height of 33,000



The height of 34,000



The height of 35,000



4.3 Analysis Calculation Results

Here is a summary of the results table or resume the calculations have been done in order to facilitate the discussion of the analysis of the parameters:

Table. 4.3.1 Comparison calculations manual with enginesim program

Altitude (ft)	TSFC (lbm/hr/lbf) EngineSim	TSFC (lbm/hr/lbf) Manual	Thermal Efficiency (%) EngineSim	Thermal Efficiency (%) Manual
25000	0,324	0,485	76,8	66,2
26000	0,323	0,486	76,6	66,3
27000	0,322	0,489	76,4	66,1
28000	0,322	0,491	76,2	66,2
29000	0,322	0,492	76,1	66,3
30000	0,323	0,496	75,9	66,1
31000	0,323	0,499	75,8	66,4
32000	0,324	0,501	75,6	66,6
33000	0,326	0,501	75,5	66,1
34000	0,327	0,502	75,4	66,4
35000	0,328	0,504	75,3	66,3

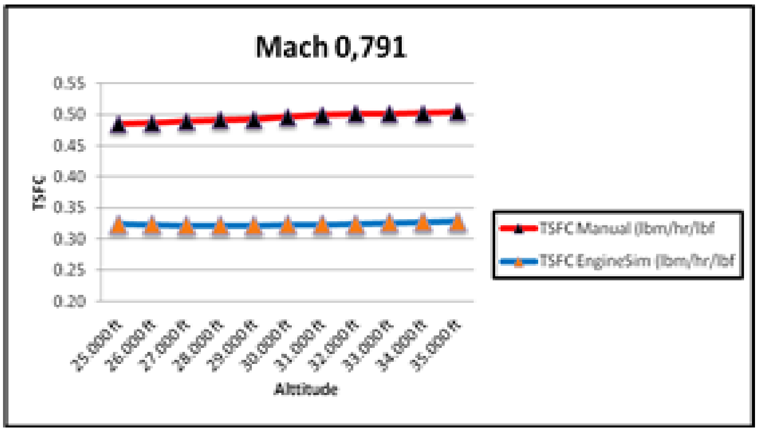


Fig. 4.3.1. TSFC vs mach

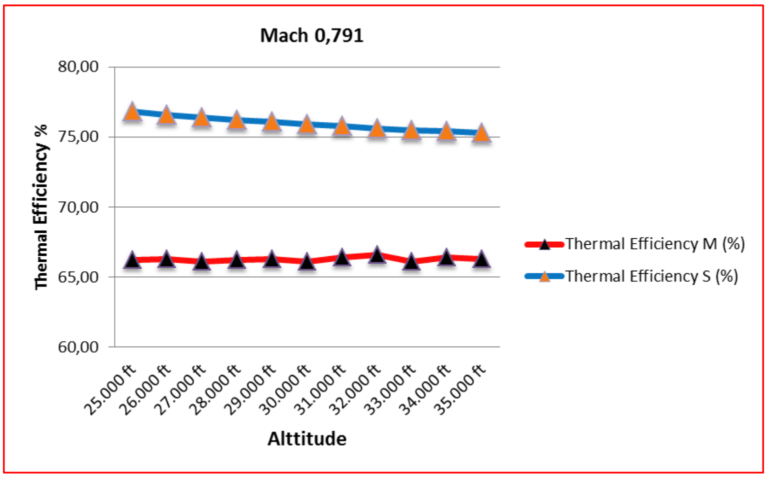


Fig. 4.3.2. Thermal efficiency vs mach

5. Conclusion

a) TSFC value either from calculations using enginesim software or manual calculation, the value enginesim TSFC with calculation software is under the maximum limit is 0.38 TSFC while manual calculation is above the maximum value TSFC.
b) Value Thermal Efficiency using EngineSim Program Average 75% while manual calculation Thermal Efficiency value is under 75%, so the calculation using the program EngineSim more efficient compared to manual calculation.

Suggestion

By intended to improvements in similar discussions, the next writer can suggest to any reader or who want to try to learn and even develop methods versus 1.7 Simulation Engine is to analyze the performance of other types such as engine Turbojet engines, ramjet and even Afterburner.

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