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 performa 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.

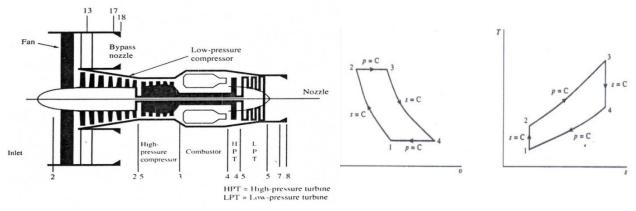


Fig 2.1. Brayton cycle diagram¹⁾

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.

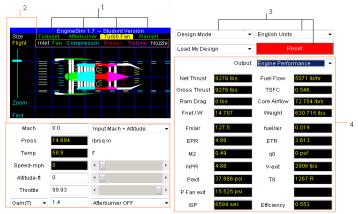


Fig 3.1. EngineSim software Display Program

- 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** : Single stage Fan 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
- $c_p = 0,240 \text{ Btu/lbm.}^0 \text{R}$
- $h_{PR} = 18400 \text{ Btu/lbm}$
- $g_c = 32.174 \text{ ft} \cdot \text{lbm}/(\text{lbf.sec}^2)$
- Turbine inlet temperature $(T_{t4}) = 2500 \text{ }^{\circ}\text{R}$
- Compressor pressure ratio (π_c) = 27,8 : 1
- Fan pressure ratio $(\pi_f) = 1,7:1$
- 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 ⁰R

Pressure ambient - P_o : 786,338 lb/ft²

Density ambient – ρ : 0,00106 slug/ft³

a) Values ideal gas constant (R):

$$R = \frac{\gamma - 1}{\gamma} c_p R = \frac{1.4 - 1}{1.4} \times (0.24 \times 778, 16) = 53,359 \text{ lbf.ft/lbm.}^{\circ} R$$

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

$$a_0 = \sqrt{\gamma \cdot R \cdot g_c \cdot T_0} = \sqrt{1.4 \times 53.359 \times 32.174 \times 429.623} = 1.016.164 \, ft/sec$$

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

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

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

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

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

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

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

$$\frac{V_{19}}{a_0} = \sqrt{\frac{2}{\gamma - 1} (\tau_r \tau_f - 1)} = \sqrt{\frac{2}{1,4 - 1} \times (1,125 \times 1,163 - 1)} = \sqrt{5 \times (0,308)}$$
$$= \sqrt{1,54} = 1,240$$

i) Thrust Specific obtained:

$$\frac{F}{m_0} = \frac{a_0}{g_c} \frac{1}{1+\alpha} \left[\frac{V_9}{a_0} - M_0 + \alpha \left(\frac{V_{19}}{a_0} - M_0 \right) \right]$$
$$= \frac{1.016,164}{32,174} \times \frac{1}{1+5,1} \times \left[2,348 - 0,791 + 5,1(1,240 - 0,791) \right]$$
$$= 31,583 \times 0,163 \times 3,846 = 19,799 lbf / lbm / sec$$

j) Fuel to Air Ratio (FAR) :

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

= $\frac{0.240 \times 429,623}{18400} \times (5,819 - 1,125 \times 2,579) = \frac{103,1095}{18400} \times (5,819 - 2,901)$
= $0.005603 \times 2,918 = 0.0163$

k) Thrust Specific Fuel Consumption (TSFC) :

$$S = \frac{f}{(1+\alpha)(F/m_0)} = \frac{0,0163}{(1+5,1)\times(19,799)} = \frac{0,0163}{6,1\times19,799} = \frac{0,0163}{120,773}$$

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

1) 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
$$(\eta T)$$

 $\eta_T = \frac{a_0^2 \left[(1+f) (V_9 / a_0)^2 + \alpha (V_{19} / a_0)^2 - (1+\alpha) M_0^2 \right]}{2.g_c \cdot f \cdot h_{PR}} \times 100\%$
 $\eta_T = \frac{983,300^2 \left[(1+0,0173) (2,609)^2 + 5,1(1,240)^2 - (1+5,1) \times 0,791^2 \right]}{2 \times 32,174 \times 0,0173 \times 18400 \times 778,16} \times 100\% = 71,87\%$

n) Propulsive Efficiency (
$$\eta_P$$
):

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

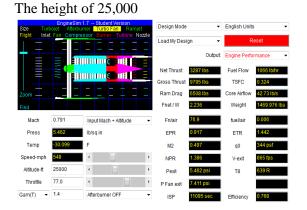
$$\eta_P = \frac{2 \times 0.791 [(1+0.0173) \times 2.609 + 5.1(1.240) - (1+5.1)0.791]}{(1+0.0173)(2.609)^2 + 5.1(1.240)^2 - (1+5.1) \times 0.791^2} \times 100\%$$

$$= \frac{1.582 [4.153]}{10.955} \times 100\% = 59.97\%$$

o) Overall efficiency (η_0): $\eta_0 = (\eta_T . \eta_P) \times 100\% \ \eta_0 = (0,7187 \times 0,5997) \times 100\% = 43,10\%$

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 26,000



The height of 27,000

Size Turk	iojet Afterbur			Design Mode	•	English Units	•
Flight Inlet	Fan Compre	ssor Burner Turbine N	lozzle —	Load My Desi	gn 👻	R	eset
+			-		Output	Engine Perfo	rmance 🔻
-≣			=	Net Thrust	3191 lbs	Fuel Flow	1028 lb/hr
	- 1			Gross Thrust	9152 lbs	TSFC	0.322
Zoom —			_	Ram Drag	5960 lbs	Core Airflow	39.459 lb/s
Find				Fnet/W	2.171	Weight	1469.976 lbs
Mach	0.791	Input Mach + Altitude	•	Fn/air	80.8	fuel/air	0.007
Press	5.003	lb/sq in		EPR	1.022	ETR	1.509
Temp	-37.219	F		M2	0.497	q0	315 psf
Speed-mph	543	•	F	NPR	1.544	V-exit	1005 fps
Altitude-ft	27000	•	F	Pexit	5.003 psi	Т8	639 R
Throttle	77.0	•	F	P Fan exit	6.788 psi		
Gam(T) 🔻	1.4	Afterburner OFF	•	ISP	11167 sec	Efficiency	0.764

The height of 29,000

	-				
Size Turi	EngineSim bojet Afterbu	1.7 Student Version Irner Turbo Fan Rar	njet	Design Mode	•
Flight Inle	t Fan Compre	essor Burner Turbine	Nozzle	Load My Desi	gn 👻
⊷ <u>+</u>			-		Output:
		III HAITIN 🤹 📲 🗍	Ξ	Net Thrust	3067 lbs
≡		₩₩₩₩ <mark>€ 061</mark>	8	Gross Thrust	8518 lbs
Zoom —				Ram Drag	5450 lbs
Find				Fnet/W	2.087
Mach	0.791	Input Mach + Altitude	-	Fn/air	84.3
Press	4.575	lb/sq in		EPR	1.135
Temp	-44.339	F		M2	0.497
Speed-mph	539	•	F	NPR	1.715
Altitude-ft	29000	•	÷	Pexit	4.575 psi
Throttle	77.0	•	F	P Fan exit	6.208 psi
Gam(T) 🔻	1.4	Afterburner OFF	•	ISP	11162 sec

The height of 31,000

		Engir	neSim 1	.7	Stude	nt Ver	sion			
Size			Afterbur							Design I
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Zoom										Ram Dr
				-						
Find										Fnet/V
		0 791								
Mach		0.791		Inp	ut Mac	n + Al	litude		•	Fn/air
Pres	5	4.177		lb/s	g in					EPR

esign Mode	•	English Units 👻			
ad My Desi	gn 👻	Reset			
	Output	Engine Perfo	rmance 🔹		
let Thrust	2927 lbs	Fuel Flow	948 lb/hr		
oss Thrust	7903 lbs	TSFC	0.323		
tam Drag	4976 lbs	Core Airflow	33.511 lb/s		
Fnet / W	1.991	Weight	1469.976 lbs		
Fn/air	87.3	fuel/air	0.0070		
EPR	1.258	ETR	1.65		
M2	0.496	q0	263 psf		
NPR	1.901	V-exit	1240 fps		
Pexit	4.196 psi	Т8	639 R		
P Fan exit	5.668 psi				
ISP	11112 sec	Efficiency	0.758		

P Fan

English Units

Fuel Flov TSFC Core Air Weight fuel/air ETR q0 V-exit т8 Effi

The height of 33,000

After ner OFF

Temp

Gam(T) - 1.4

Press

Temr Speed-mph Altitude-ft 33000 77.0 Throttle

Gam(T) - 1.4

310 Altitude-ft

77.0 Throttle

Spee

		gincollin i.i.		31011	De
Size	Turbojet	Afterburner	Turbo Fan	Ramjet	De
Flight	Inlet Fan	Compressor	Burner T	urbine Nozzle	
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Zoom-					Ra
Find					F
Mach	0.79	1 Inp	ut Mach + Al	titude •	•

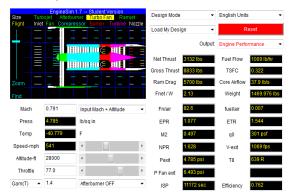
lb/sq in

Afterburner OFF

F F

Design Mode	•	English Units 👻		
Load My Des	ign 👻	Reset		
	Output:	Engine Perfo	rmance -	
Net Thrust	2779 lbs	Fuel Flow	906 lb/hr	
Gross Thrust	7315 lbs	TSFC	0.326	
Ram Drag	4535 lbs	Core Airflow	30.817 lb/s	
Fnet/W	1.89	Weight	1469.976 lbs	
Fn/air	90.1	fuel/air	0.0080	
EPR	1.39	ETR	1.724	
M2	0.496	q0	240 psf	
NPR	2.101	V-exit	1342 fps	
Pexit	4.227 psi	T8	639 R	
P Fan exit	5.168 psi			

The height of 28,000



The height of 30,000

		1.7 Student Version	5
		imer Turbo Fan Ramjet	I
Flight Ir	ilet Fan Compre	essor Burner Turbine Nozzle	Ē.
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	= = 19		
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	- + -		
Zoom -			
Find			
Mach	0.791	Input Mach + Altitude 👻	
Press	4.373	lb/sg in	
Temp	-47.899	F	
Speed-mp	h 536		
opeed-mp			
Altitude-ft	30000	< F	
	77.0		
Throttle	77.0	4 F	
Gam(T)	▼ 1.4	Afterburner OFF 🔹	

et	Design Mode	•	English Units	•
ozzie	Load My Desi	gn 🔻	R	eset
		Output:	Engine Perfo	rmance 🔹
	Net Thrust	2999 lbs	Fuel Flow	969 lb/hr
2	Gross Thrust	8207 lbs	TSFC	0.323
_	Ram Drag	5208 lbs	Core Airflow	34.927 lb/s
	Fnet / W	2.04	Weight	1469.976 lbs
•	Fn/air	85.8	fuel/air	0.007
	EPR	1.195	ETR	1.614
	M2	0.496	qQ	275 psf
÷	NPR	1.806	V-exit	1186 fps
F	Pexit	4.373 psi	T8	639 R
F.	P Fan exit	5.933 psi		
•	ISP	11141 sec	Efficiency	0.759

The height of 32,000

		n 1.7 Student Version				
		urner Turbo Fan Ramjet				
Flight Init	et Fan Compr	essor Burner Turbine Nozzle				
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Mach	0.791	Input Mach + Altitude 👻				
Press	3.989	Ib/sq in				
_	55.040	. .				
Temp	-55.019	F				
Temp Speed-mph	-55.019 532	F				
Speed-mph	532	< •				
Speed-mph Altitude-ft	532	< •				
Speed-mph	532 32000	<				

	Design Mode	•	English Units	•
zie —	Load My Desi	gn 🔻	R	eset
-		Output	Engine Perfo	rmance 🔹
=	Net Thrust	2854 lbs	Fuel Flow	927 lb/hr
2	Gross Thrust	7606 lbs	TSFC	0.324
_	Ram Drag	4751 lbs	Core Airflow	32.142 lb/s
	Fnet/W	1.941	Weight	1469.976 lbs
•	Fn/air	88.8	fuel/air	0.008
	EPR	1.323	ETR	1.687
	M2	0.496	q0	251 psf
F.	NPR	1.999	V-exit	1292 fps
F	Pexit	4.214 psi	T8	639 R
F.	P Fan exit	5.413 psi		
•	ISP	11080 sec	Efficiency	0.756

The height of 34,000

	EngineSim 1	1.7 Student V	ersion				
	urbojet Afterbur			Design Mode	•	English Units	•
Flight In	let Fan Compre	ssor Burner	Turbine Nozzle	Load My Desi	gn 🔻	R	eset
+					Output:	Engine Perfo	rmance 👻
				Net Thrust	2703 lbs	Fuel Flow	884 lb/hr
				Gross Thrust	7031 lbs	TSFC	0.327
Zoom				Ram Drag	4327 lbs	Core Airflow	29.535 lb/s
Find				Fnet/W	1.838	Weight	1469.976 lbs
Mach	0.791	Input Mach + /	Altitude 👻	Fn/air	91.5	fuel/air	0.008
Press	3.634	lb/sq in		EPR	1.46	ETR	1.763
Temp	-62.139	F		M2	0.496	q0	229 psf
Speed-mpl	h 527	•	F	NPR	2.206	V-exit	1390 fps
Altitude-ft	34000	•	F	Pexit	4.236 psi	Т8	639 R
Throttle	77.0	4	•	P Fan exit	4.931 psi		
Gam(T)	- 1.4	Afterburner Of	FF 👻	100	10007.000		0.754

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:

Altitude	TSFC	TSFC	Thermal	Thermal
(ft)	(lbm/hr/lbf)	(lbm/hr/lbf)	Efficiency	Efficiency
	EngineSim	Manual	(%) EngineSim	(%) 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

Table. 4.3.1 Comparison calculations manual with enginesim program

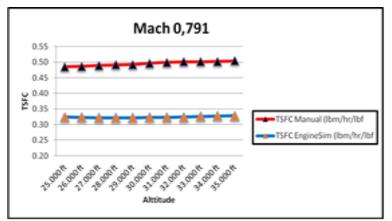


Fig. 4.3.1. TSFC vs mach

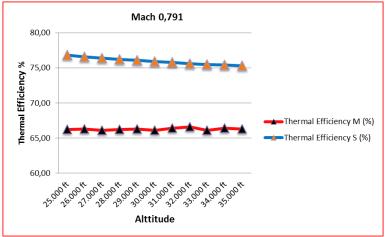


Fig. 4.3.2. Thermal efficiency vs mach

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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