AE 234 Course Project

Group - 10

~Sayan Vishwakarma(210010058)

~Sahil Nitin Kale(210010054)

~Keyur Bagadiya(210010019)

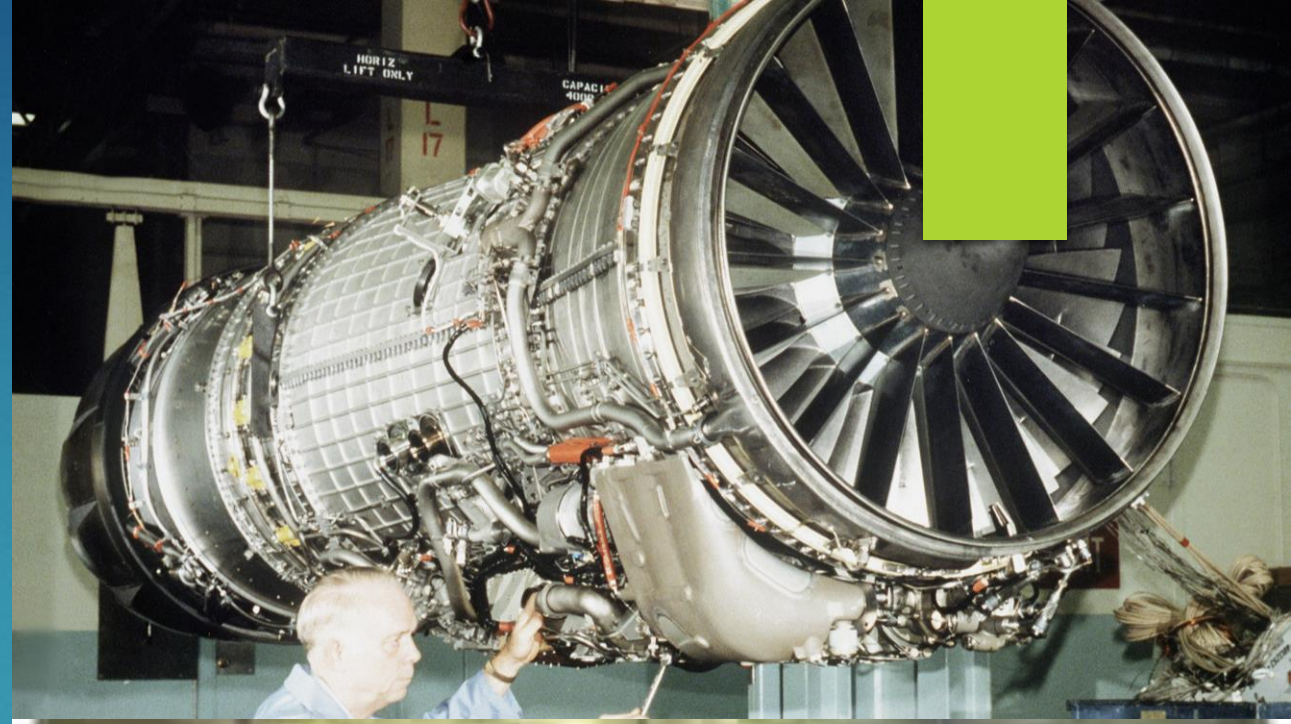
~Utkarsh Kamal (210010066)

Professor : Krishnendu Sinha

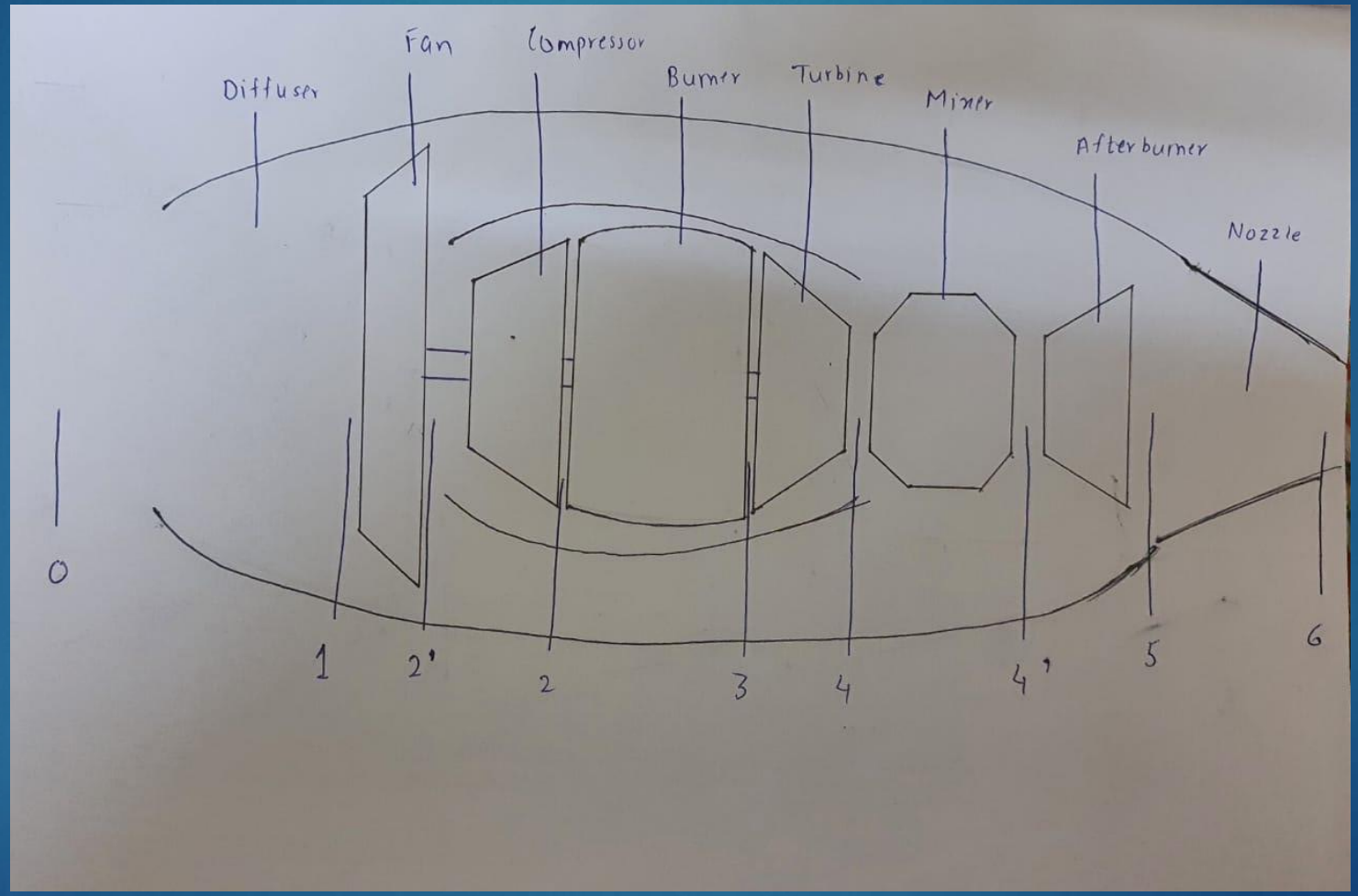
Objective

Cycle analysis of GEF – 101 turbofan engine:

Detailed analysis of each of the component in the engine to obtain Thrust and TSFC



Engine schematic



Engine Parameters

- Design Point Mach Number(M_0) = 1.25
- Altitude(h) = 15.2 KM
- Intake : η_d = 0.94
- Fan : $\pi_f = 2.3$, η_f = 0.8
- Compressor : $\pi_c = 11.65$, η_f= 0.87
- Burner: η_b = 0.97, $\dot{Q}_R = 47.2\ MJ/Kg, \dot{m}_f = 0.7\ kg/s$; $C_{p1}(Pre\ Combustor) = 1005\text{J/Kg}$ $C_{p2}(Post\ Combustor) = 1090\ J/KgK$
- Turbine : η_t = 0.89
- Afterburner :$\dot{m}_{ab} = 2\ kg/s$, η_{ab} = 0.97, $C_{p3}(Post\ afterburner) = 1098\text{J/KKg}$
- Nozzle : NPR = 4.98, η_n= 0.94

Diffuser

Known parameters are :

$\eta_d = 0.94$ $M_0 = 1.25$

$P_o = 12$ kPa

We know the relations for diffuser as ;

- $\tau_r = \frac{T_{to}}{T_o} = (1 + \frac{\gamma - 1}{2} M_0^2)$
- $\frac{P_{t1}}{P_o} = (1 + \eta_d \frac{\gamma - 1}{2} M_0^2)^{\frac{\gamma}{\gamma - 1}}$

- Hence, $T_{to} = T_{t1} = 284.35$ K ; $P_{t1} = 29.66\ kPa$

Fan

- Bypass ratio = $\alpha = \frac{\dot{m}_{bypass}}{\dot{m}_{core}} = 2$
- $\eta_f = \frac{h_{t_{2\prime s}} - h_{t1}}{h_{t_{2\prime}} - h_{t1}} = \frac{\pi_f^{\frac{\gamma-1}{\gamma}} - 1}{\tau_f - 1}$
- $\pi_f = \frac{P_{t2\prime}}{P_{t1}} = 2.3$
- $\eta_f = 0.8$
- $\tau_f = \frac{T_{t2\prime}}{T_{t1}} = 1.335$
- $T_{t2\prime} = 379.85\ K$; $P_{t2\prime}$ = 68.23 kPa

Compressor

- $\pi_c = \frac{P_{t2}}{P_{t1}} = 11.65$
- $\frac{T_{2s}}{T_{t1}} = \pi_c^{\frac{\gamma-1}{\gamma}}$
- $\frac{T_{t2}}{T_{t1}} = \tau_c$
- $\eta_c = \frac{h_{t2s}-h_1}{h_{t2}-h_1} = \frac{\frac{h_{t2s}}{h1}-1}{\frac{h_{t2}}{h1}-1} = \frac{\pi_c^{\frac{\gamma}{\gamma-1}}-1}{\tau_c-1}$
- η_c = 0.87
- τ_c = 2.17
- T_{t2} = 823.85 K ; P_{t2} = 345.66 kPa

Burner

Using energy conservation in burner as follows;

- We know; $\eta_b = 0.97,\ \dot{Q}_R = 47.2\ MJ/Kg, \dot{m}_f = 0.7\ kg/s$
- $(\dot{m}_c + \dot{m}_{f,c})C_{p2}T_{t3} - \dot{m}_{f,c}C_{p1}T_{t2} = \eta_b \dot{Q}_R \dot{m}_{f,c}$
- Hence from the equation we get;
- $T_{t3} = 1540\ \mathrm{K}$

Turbine

- $\frac{T_{4s}}{T_{t3}} = \pi_t^{\frac{\gamma-1}{\gamma}}$
- $\frac{T_{t4}}{T_{t3}} = \tau_t$
- $\eta_t = \frac{h_{t3}-h_{t4}}{h_{t3}-h_{4s}} = \frac{1-\tau_t}{1-\pi_t^{\frac{\gamma-1}{\gamma}}}$
- η_t = 0.89
- From Power balance of turbine, compressor and fan;
- T_{t4}= 956 K
- τ_t = 0.619
- $\pi_t = \frac{P_{t4}}{P_{t3}} = 0.142$
- P_{t4} = 48.94 kPa

Mixer

For bypass flow;

- $\dot{m}_{bypass} = 74.73$ Kg/s
- $T_{bypass} = T_{t2'} = 379.85$ K
- $C_{P,bypass} = C_{P1} = 1005$ J/KgK

For core flow;

- $\dot{m}_{core} = 37.37$ Kg/s
- $T_{core} = T_{t4} = 956$ K
- $C_{P,core} = C_{P2} = 1090$ J/KgK

From energy conservation;

$(\dot{m}_{core}+\dot{m}_{f,c})(T_{t4} - T_{t4'})\ C_{P2} = \dot{m}_{bypass} C_{P1}(T_{t4'} - T_{t2'}) \Rightarrow T_{t4'} = 588$ K

After Burner

- Using energy conservation in burner as follows;
- We know;
- $\dot{m}_{ab} = 2\ kg/s$, $\eta_{ab} = 0.97$,
- $C_{p3}(Post\ afterburner) = 1098$J/KKg, γ(post) = 1.3
- Using energy balance;
- $(\dot{m}_o + \dot{m}_{ab} + \dot{m}_{f,c})C_{p3}T_{t5} - \dot{m}_{ab}C_{p2}T_{t4'} = \eta_{ab}\dot{Q}_R\dot{m}_{ab}$
- Hence from the equation we get;
- $T_{t5} = 1310$ K

Nozzle

Known parameters are :

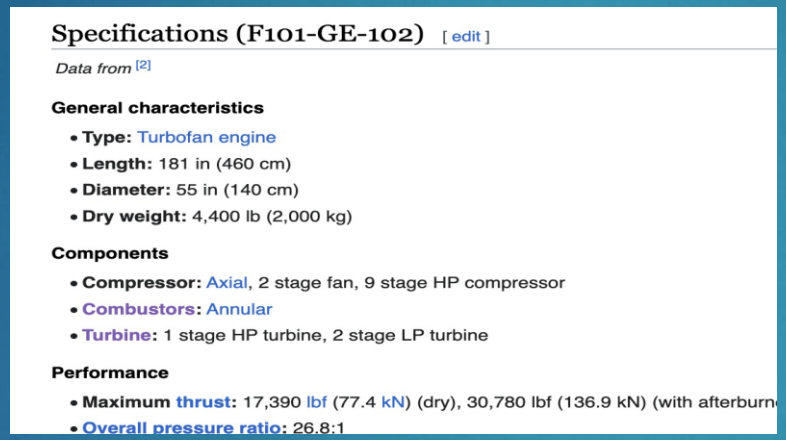
- $\eta_n = 0.94$
- $\text{NPR} = \frac{P_{t6}}{P_6} = 4.98$
- $P_6 = P_o = 12$ kPa
- We know the relations for diffuser as ;
- $\eta_n = \frac{\text{NPR}^{\frac{\gamma-1}{\gamma}} - \pi_n^{\frac{1-\gamma}{\gamma}}}{\text{NPR}^{\frac{\gamma-1}{\gamma}} - 1}$
- $\pi_n = \frac{P_{t6}}{P_{t5}} = 1.87$
- $\frac{P_{t6}}{P_6} = \left(1 + \frac{\gamma-1}{2} M_e^2\right)^{\frac{\gamma}{\gamma-1}}$, $\frac{T_{t6}}{T_6} = \left(1 + \frac{\gamma-1}{2} M_e^2\right)$
- Hence, $T_6 = 327$ K ; $M_e = 4.49$

Performance parameters

- $V_e = M_e\sqrt{\gamma R T_e} = 1570.75$ m/s
- $V_o = M_o\sqrt{\gamma R T_o} = 368.80$ m/s
- Thrust(T) = $V_e(\dot{m}_0 + \dot{m}_{f,c} + \dot{m}_{ab}) - \dot{m}_0 V_o = 137$ kN
- TSFC = $\frac{\dot{m}_f + \dot{m}_{f,ab}}{T} = 68.13$ kg/kNh

References

- AIAA PAPER No 75-1308(GE – F101 Structure) : https://arc.aiaa.org/doi/pdf/10.2514/6.1975-1308
- F-101 engine combustion system: https://apps.dtic.mil/sti/pdfs/ADA077860.pdf
- Wikipedia :



Specifications (F101-GE-102) [edit]

Data from [2]

General characteristics

- **Type:** Turbofan engine
- **Length:** 181 in (460 cm)
- **Diameter:** 55 in (140 cm)
- **Dry weight:** 4,400 lb (2,000 kg)

Components

- **Compressor:** Axial, 2 stage fan, 9 stage HP compressor
- **Combustors:** Annular
- **Turbine:** 1 stage HP turbine, 2 stage LP turbine

Performance

- **Maximum thrust:** 17,390 lbf (77.4 kN) (dry), 30,780 lbf (136.9 kN) (with afterburn
- **Overall pressure ratio:** 26.8:1

- Calculation work : https://docs.google.com/spreadsheets/d/1IXztg6qBeyn3groeU3VipttltI9k7H3TK5i3rz7fXL6c/edit?usp=sharing

- Some of the parameters are assumed due to lack of data

THANK YOU!