COMPARATIVE ANALYSIS FOR PERFORMANCE PREDICTION IN CASE OF IAR 99 AIRCRAFT PROPULSION SYSTEMS

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***Abstract**: This paper presents a comparative analysis regarding Performance Prediction at Design and Off-Design Regimes, applied for two distinct constructions of Jet Engines as Propulsion Systems solutions for the IAR 99 Aircraft. Case Study #1 is represented by Turbojet Engine Rolls Royce VIPER MK 632-41 and Case Study #2 is represented by a Mixed Flows Turbofan Engine. The thorough study is based on appropriate Applicable Theory, which is detailed in the bibliographic references and can be accessed. Applicable Theory includes a part dedicated to Engine Parameter Identification, which is necessary to calculate Brayton Diagram and the performances of the jet engines, expressed as Thrust and Specific Fuel Consumption (TSFC). Applicable Theory includes detailed Mathematical Modeling, Developments and Numerical Simulations for Turbojet Engine and Mixed Flows Turbofan Engine.*

Performance Prediction results from aero-thermo-gas dynamics analysis of the studied engines. The accuracy of the numerical results depends on the assumptions used for mathematical modeling, which in this case have been considered: real gas, adiabatic flow, the variation with static temperature of the specific heat, losses due to pressure drop and friction, the conditions for full expansion in the exhaust nozzle are met such that the engine can generate maximum of Thrust. Results from Numerical Simulations express Performance Prediction for the Turbojet Engine and the Mixed Flows Turbofan Engine, for the Design and Off-Design Regimes. Comparative diagrams illustrating the variation of Thrust and Specific Fuel Consumption (TSFC) with Mach number and altitude, for the studied jet engines, conclude the analysis. As final remark, the Mixed Flows Turbofan Engine represents a better option than the Turbojet Engine, from the standpoint of greater Thrust and lower TSFC.

***Keywords**: Performance Prediction, Jet engines, Turbojet, Mixed Flows Turbofan, Design Regime, Off-Design Regimes, IAR 99 Aircraft, Propulsion Systems.*

1. INTRODUCTION

This paper is focused on Performance Prediction at Design and Off-Design Regimes, with application to the Turbojet Engine and Mixed Flows Turbofan engines, intended as Propulsion System solutions for the IAR 99 Aircraft. This study presents numerical simulations for performance prediction at Design Regime and Off-Design Regimes in case of turbojet engine versus mixed flows turbojet engine, by using in-house developed codes, based on algorithms from mathematical modeling of the Turbojet Engineand Mixed Flows Turbojet Engine.

The scope of this study is to present a comparative analysis of the performances for the two distinct constructions and based on the calculations, to formulate the final conclusion, i.e. to highlight the best option from the standpoint of Thrust and Specific Fuel Consumption (TSFC). The investigation expresses the variation of Thrust and TSFC with the flight velocity or Mach number and altitude, for Design and Off-Design Regimes.

Case Study #1 is represented by Turbojet Engine Rolls Royce VIPER MK 632-41while Case Study #2 is represented by a Mixed Flows Turbofan Engine.

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It comes up that the Mixed Flows Turbofan Engine represents a better option than the Turbojet Engine, from the standpoint of greater Thrust, lower TSFC and availability of Mixed Flows Turbofan Engine for delivering greater thrust for all the flying regimes described by the aircraft flight envelope and engine operating regimes, with respect to the Turbojet Engine, which is able to deliver greater thrust for limited time intervals and for certain operating conditions (as Reheat being activated) and specific additional constructions (as the Afterburner Unit).

2. DESCRIPTION OF POTENTIAL SOLUTIONS AND CASE STUDIES

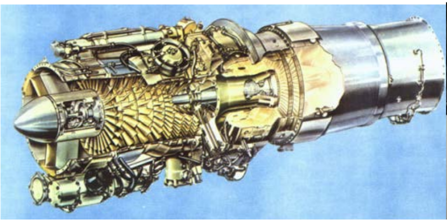
2.1.Overview

Case Studies are represented by the options as propulsion systems for the IAR 99 ȘOIM Advanced Trainer and Light Attack Aircraft. Therefore, Case Study #1 is represented by Turbojet Engine Rolls Royce VIPER MK 632-41, powering the IAR 99 ȘOIM Aircraft, Fig.4 and Fig. 5, while Case Study #2 is represented by a Mixed Flows Turbofan Engine, powering the IAR 99 TD Aircraft, Fig. 6 and Fig. 11.

FIG. 1 IAR 99 ȘOIM Advanced Trainer and Light Attack Aircraft

FIG. 2 IAR 99 ȘOIM NO. 7003/2006

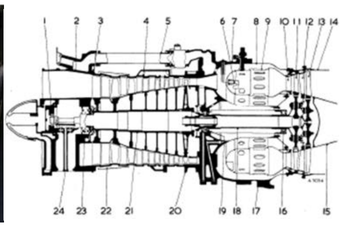
FIG. 3 IAR 99 TD



a) Cutview

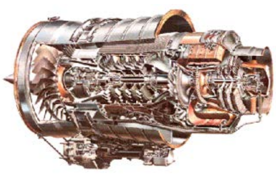
b) Cutaway

FIG. 4 Rolls Royce VIPER MK 632-41Turbojet Engine



Schematic Diagram

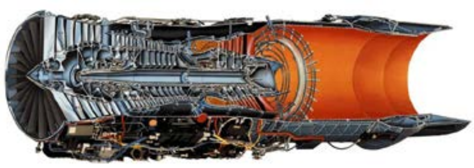
FIG. 5 Rolls Royce Viper 632-41 Turbojet Engine



a) Cutview

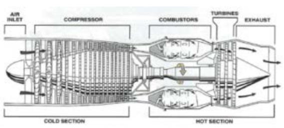
b) Sideview

FIG. 6 Mixed Flows Turbofan Engine

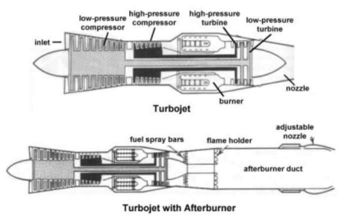


Cutview

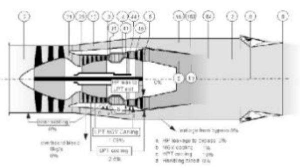
FIG. 7 Mixed Flows Turbofan Engine with Afterburner



a) Turbojet

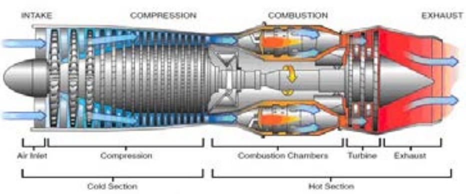


b) Turbojet vs. Turbojet with Afterburner

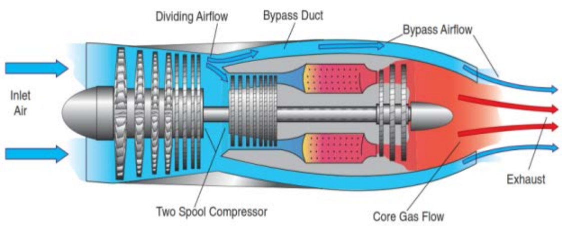


c) Mixed Flows Turbofan with Afterburner

FIG. 8 Jet Engine Schematic Diagram

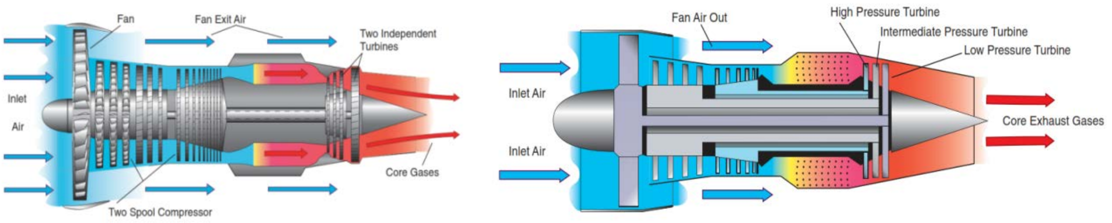


a) Turbojet Engine



b) Mixed Flows Turbofan Engine

FIG. 9 Jet Engines vector Iillustration diagram



c) SeparateFlowsTurbofanEngine, twin-spoolconstruction

d) SeparateFlowsTurbofanEngine, triple-spoolconstruction

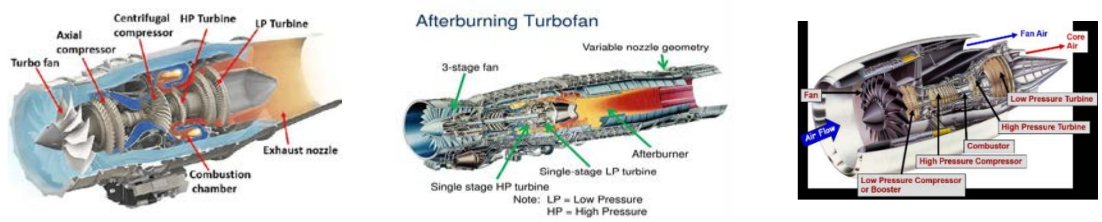
FIG. 9 Jet Engines Vector IllustrationDiagram

2.2.Considerations on changing the solution for powering the IAR 99 Aircraft:

1/ **Initial configuration**: the IAR 99 ȘOIM Advanced Trainer and Light Attack Aircraft is powered by Rolls Royce VIPER MK 632-41, which is a Turbojet Engine equipped with an Afterburner, as shown in Fig. 4, Fig. 8-a,b and Fig. 9-a. The justification for the Afterburner comes results from the fact that it enables to augment the Thrust, but only for specific aircraft flight evolutions and for short time intervals, whilst the reheat is engaged. The limitation in time results from the significant increase of the fuel consumption, due to the operation of the Afterburner.

2/ **Potential options**: the IAR 99 Aircraft might be powered by a category of Turbofan Engines, Fig. 9-b, represented by either Separate Flows Turbofan, Fig. 10-c, or Mixed Flows Turbofan, Fig. 10-a. The reason for the use of Turbofan Engines consists in the fact that the engine delivers increased thrust with respect to the Turbojet Engine, for all the aircraft evolutions described in the flight envelope, throughout all the flight phases, without time limitations.

- Since the **Separate Flows Turbofan**, Fig. 10-c, is operating on high bypass ratio, then the forward cross section is supposed to be large, that is with large diameter on engine inlet. In case of military aircraft, the cross section should be minimized, such that the aircraft drag should be maintained during flight as least as possible. The reheat can be organized on the core flow, in case of the Separate Flows Turbofan, but it comes with the penalty of increased drag and lower engine efficiency. Therefore, it results that theSeparate Flows Turbofan is not a suitable option for powering the IAR 99 Aircraft.
- The **Mixed Flows Turbofan**, Fig. 10-a, is operating on low bypass ratio, thus it requires a minimized cross-section and therefore determining reduced aircraft drag and reduced fuel consumption. The reheat can be organized on the core flow, in the mixing area, which is delimitated by the LP turbine exit and exhaust nozzle inlet, Fig. 10-a. The schematic diagram of the Mixed Flows Turbofan is indicated in Fig. 8-c. The Afterburning Turbofan, Fig. 7 and Fig. 10-b, delivers larger Thrust values.



a) Mixed Flows Turbofan Engine b) Afterburning TurbofanEngine c) Separate Flows Turbofan Engine

FIG. 10 Jet Engines Vector IllustrationDiagram

3/ **The effective solution** consists in shifting the afterburning Turbojet Engine Rolls Royce VIPER MK 632-41 with a Geared Mixed Flows Turbofan Engine, Fig.11, which can deliver comparable thrust and TSFC range for similar flight envelope and engine operational regimes.

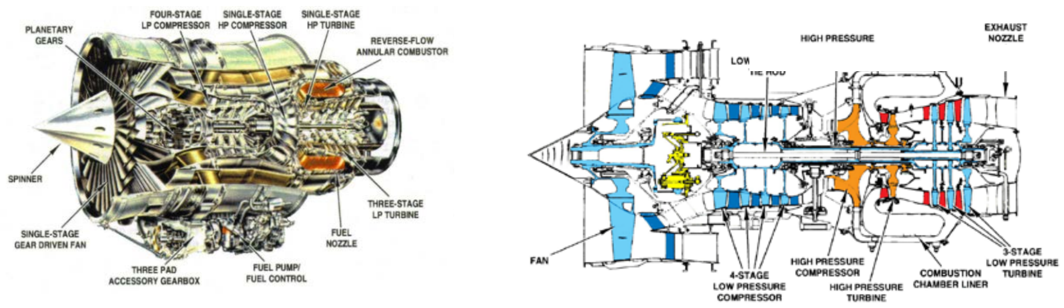


FIG. 11 GearedMixedFlowsTurbofanEngine

Engine data and specifications for Case Study #1: *Turbojet Engine Rolls Royce VIPER MK 632-41.*
Type: Turbojet Engine*, single spool*
Manufacturer*: Rolls-Royce*
Application*: IAR-93A, IAR99Şoim, J-22A, G-4 Super GalebAircraft,*
Engine Design*:subsonic inlet, 8 axial compressor stages, annular combustor, 2 axial turbine stages, variable geometry exhaust*
D-inlet*: 0.747m,* ***W****=376kg,* ***Length:*** *1.55m,* ***Width:*** *0.706m,* ***Height:*** *0.84m,* ***Length of jet pipe:*** *2m,*
Static sea level performances*:*
Thrust *(SSL – static, Sea Level)* ***T-ssl****=17659N*
T-ssl-AB *(SSL, AB – Afterburner) =22241N*
Specific Fuel Consumption SFC-ssl*=2.75e-05kg/Ns*
Air Mass Flow Rate *=26.3kg/s,* ***Pressure Ratio****=6,* ***Turbine InletTemperature: 1249****K.*

Compressor
- *Compressor assembly consists of rotor and casing,*
- *Rotor is mounted on 2 main bearings and has eight stages,*
- *Materials: 1^{st}, 2^{nd} and last stage: steel, the rest, light alloy,*

Combustion section
- *Components: compressor diffuser, outer casing, annular combustor,*
- *The diffuser has blade units to guide the flow,*

Turbine
- *Components: two stages, disc unit type, each preceded by stator guide vanes (i.e. cascade of stator blades),*

Exhaust cone
- *Bolted to the combustion chamber outer casing.*

In Fig. 5 are highlighted the main parts: 3/ Compressor casing, 8/ Combustion chamber casing, 10/ Turbine first stage stator blades, 11/ Turbine first stage rotor blades, 12/ Turbine second stage stator blades, 13/ Turbine second stage rotor blades, 14/ Exhaust outer cone, 15/ Exhaust inner cone, 16/ Rear main bearing, 18/ Turbine main shaft, 19/ Centre main bearing, 23/ Front main bearing.

Engine data and specifications for Case Study #2: *Mixed Flows Turbofan Engine.*
Type: Mixed Flows Turbofan Engine*, twin spool*
Application*: IAR 99 TD Aircraft,*
Engine Design*: high velocity inlet,* ***Low Pressure*** *LP rotor assembly: 4 axial compressor stages, 3 axial turbine stages,* ***High Pressure HP*** *rotor assembly: 1 centrifugal compressor stage, 1 axial turbine stage, annular combustor, fixed/ variable geometry exhaust,*
D-inlet*: 0.747m,* ***W****=401,43kg,* ***Length:*** *1.54m,* ***Width:*** *0.85m,* ***Height:*** *1m,*

Static sea level performances:
Thrust *(SSL – static, Sea Level)* ***T-ssl****=17570N*
Specific Fuel Consumption SFC-ssl*=2.5e-05kg/Ns*
Overall Air Mass Flow Rate *=65.3kg/s,* ***Core Flow Air Mass Flow Rate*** *=16.86kg/s,*
Bypass Air Mass FlowRate *= 48.91kg/s,* ***Bypass Ratio****: 2.9,*
Pressure Ratio*:22(cycle/core flow), 1.76 (fan),* ***Turbine InletTemperature: 1410****K.*

The geared twin-spool turbofan engine is controlled by a single-channel, digital electronic engine control(DEEC) with a hydro mechanical backup fuel control unit (FCU). The DEEC governs low-pressure (LP) spool speed (N1) based on engine inlet temperature (T2), inlet pressure (P2), power lever angle (PLA), weight-on-wheels (WOW), and flight Mach number. The DEEC provides inter-stage turbine temperature (ITT) and spool speed limiting functions, auto-ignition, hung start protection, fault detection and accommodation logic.

3. APPLICABLE THEORY

3.1 APPLICABLE THEORY - Engine Parameter Identification

Details on Engine Parameter Identification are provided in paper [2], published in INCAS Bulletin:

[2] Irina Carmen ANDREI, Mihai Victor PRICOP, Mihai L. NICULESCU, Andreea CERNAT, **The completion of the mathematical model by parameter identification for simulating a turbofan engine**, INCAS BULLETIN, 2015, Volume 7, Issue 3/ 2015, pp. 25-37, ISSN 2066 – 8201, https://old.incas.ro/images/stories/INCAS_BULLETIN/ INCAS_Bulletin_Vol_7_Iss_3_2015_Internet.pdf

Parameter identification, in case of the Mixed Flows Turbofan Engine, provided for the specified Altitude leveles, Table 1, Flight Velocity, Table 2, Engine Input Data, Table 3, Performance Refernce Values, Table 4, which allow to determineTurbine Inlet Temperature T3T = 1410 [K], fan pressure ratio and and specific fan work, from the deduced non-linear equation (1), or any its equivalent (2÷4), [2].

Table 1. Altitude levels, [2]:

H [ft]	0	10000	20000	30000	40000
H [km]	0	3.048	6.096	9.144	12.192

Table 2. Flight velocity, [2]:

Cruise	Mach = 0.7

Table 3. Engine Input data, [2]:

Pressure ratios – c (*compressor*), f (*fan*)	$\pi_c^* = 22$	$\pi_v^* = 1.76$
Bypass ratio BPR	$K = 2.9$	
Airflow Rate [kg/s]	$\dot{M}_a = 65.772$	

Table 4. Reference performance values, [2]:

Conditions // regimes	Net thrust [N]	Fuel specific consumption [kg/Nh]
Thermodynamic, Sea Level, Static, ISA	20907	0.04650
Takeoff, Sea Level, Static (available to 303 [K])	18905	0.04660
Max Cruise, Mach 0.8 (ISA), 40000[ft] = 12.19 [km]	4493	0.07536

$$f\left(l_v^*\right)=\left(\frac{k_g}{k_g-1}\right)\cdot\ln\left(1-\left(\frac{l_c^*+K\cdot l_v^*}{\eta_t^*\cdot i_3^*}\right)\right)\pi_c^*-\left(\frac{k}{k-1}\right)\cdot\ln\left(1+\left(\frac{l_v^*\cdot\eta_v^*}{i_1^*}\right)\right) \quad (1)$$

$$fp\left(l_v^*\right)=\pi_c^*\cdot\sigma_{ca}^*\cdot\left(1-\left(\frac{l_c^*+K\cdot l_v^*}{\eta_t^*\cdot i_3^*}\right)\right)^{\left(\frac{k_g}{k_g-1}\right)}-\left(1+\left(\frac{l_v^*\cdot\eta_v^*}{i_1^*}\right)\right)^{\left(\frac{k}{k-1}\right)} \tag{2}$$

$$l_c^*=i_1^*\cdot\frac{\left(\left(\pi_c^*\right)^{\left(\frac{k}{k-1}\right)}-1\right)}{\eta_c^*} \tag{3}$$

$$l_v^*=i_1^*\cdot\frac{\left(\left(\pi_v^*\right)^{\left(\frac{k}{k-1}\right)}-1\right)}{\eta_v^*} \tag{4}$$

The argument of both functions*f* (1) and *fp* (2) is the specific work of fan; the correlation between fan pressure ratio and specific work is expressed by equations (3) for the compressor and (4) in case of the fan. The solution of the equation is the parameter Fan Specific Work (4), obtained from Newton-Raphson algorithm or the chords method. Since there is a single non-linear equation with two parameters (the temperature T3T and the fan specific work), the non-determination is off if one parameter is set to a certain reference value (in this case, the temperature T3T) and the other is obtained numerically. The search is continued until one obtains that the calculated fan pressure ratio reaches the value specified for the fixed point, that is 1.76.

3.2 APPLICABLE THEORY - Predicted Performances of the Turbofan Engine:

The performances of the mixed flows turbofan are the specific thrust F_{sp}[Ns/kg] (5), the thrust F [N] (6), where the variation of the airflow rate on core flow with the altitude and Mach number is given by relation (7) and fuel specific consumption C_{sp}[kg/Nh] (8).

$$F_{sp}=\left(1+K\right)\cdot C_{5\_am}-V \tag{5}$$

$$F=F_{sp}\cdot\dot{M}_{a1}-V \tag{6}$$

$$\dot{M}_{a1}=\dot{M}_{a10}\cdot\frac{\pi_c^*}{\pi_{c0}^*}\cdot\pi_d^*\cdot\frac{p_H}{p_0} \tag{7}$$

$$C_{sp}=\frac{3600}{F_{sp}}\cdot\frac{\left(i_3^*-i_2^*\right)}{\left(P_{ci}\cdot\xi_{ca}-i_3^*\right)} \tag{8}$$

3.3 APPLICABLE THEORY - Numerical Simulations and Results

Table 5. Fan Specific Work – as solutions of equation (1), depending on Fan Pressure Ratio and T3T, search on narrow T3T (Turbine Inlet Temperature)intervals and Fan Pressure Ratio, [2]

$T_3^*\left[K\right]$	$l_v^*\left[kJ/kg\right]$	π_v^*
1403	**58.955**	**1.74960491**
1410	**59.657**	**1.760399 ≈ 1.76**
1433	**61.946**	**1.79591531**

Table 6. Fan Specific Work – as solutions of equation (1), depending on Fan Pressure Ratio and T3T, search on large T3T (Turbine Inlet Temperature)intervals and Fan Pressure Ratio, [2]

$T_3^*[K]$	$l_v^*[kJ/kg]$	π_v^*
1175	34.576	1.4032669
1275	45.644	1.55375834
1300	48.317	1.59175686
1375	56.121	1.70650774
1403	**58.955**	**1.74960491**
1433	**61.946**	**1.79591531**
1800	95.065	2.3691199
1850	99.135	2.44756941
1900	103.11	2.52597691

Table 7. Convergence history, [2]

$T_3^* = 1403[K]$		$T_3^* = 1410[K]$		$T_3^* = 1433[K]$	
$\pi_v^* = 1.76$	**1.74960491**	$\pi_v^* = 1.76$	**1.760399 ≈ 1.76**	$\pi_v^* = 1.76$	**1.79591531**
$l_v^*[kJ/kg]$	*f(x)*	$l_v^*[kJ/kg]$	$l_v^*[kJ/kg]$	$l_v^*[kJ/kg]$	$l_v^*[kJ/kg]$
20	0.9161455	20	0.92829367	20	0.96712693
80	-0.51281138	80	-0.49296558	80	-0.42977795
58.467732	0.01169386	59.188924	0.01117993	61.540134	9.53214253e-3
58.947794	1.76622721e-4	59.65043	1.60274878e-4	61.940676	1.14163633e-4
58.955156	-5.57984042e-8	59.657142	-4.78878279e-8	61.945531	-2.80520026e-8
58.955154	2.65898414e-13	59.65714	2.06057393e-13	61.94553	8.12683254e-14
58.955154	1.44328993*e-15	59.65714	0	61.94553	0
58.955154	0	59.65714	0	61.94553	0

3.4 APPLICABLE THEORY – Mathematical Modeling, Developments, Numerical Simulations

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3.5 APPLICABLE THEORY - Intermediate Results for Engine Performance Prediction at Design and Off-Design Regimes

1/ Temperature and pressure variation with altitude,

$$T_H = T_0 - 6.5 * H \qquad p_H = p_0 * \left(\frac{T_H}{T_0} \right)^{5.2553}$$

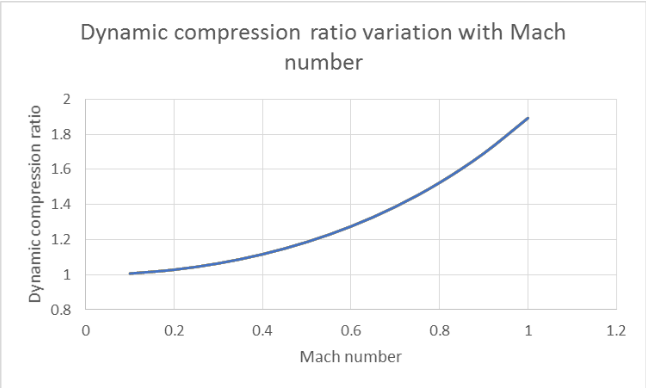
2/ Thermodynamic function with respect to Mach number or the ratio of stagnation to static temperature,

$$\theta(M) = \left(1 + \frac{k-1}{2} * M^2 \right) \qquad \theta(M) = \left(\frac{T^*}{T} \right)$$

3/ Correlation of velocity and Mach number; Sound velocity,

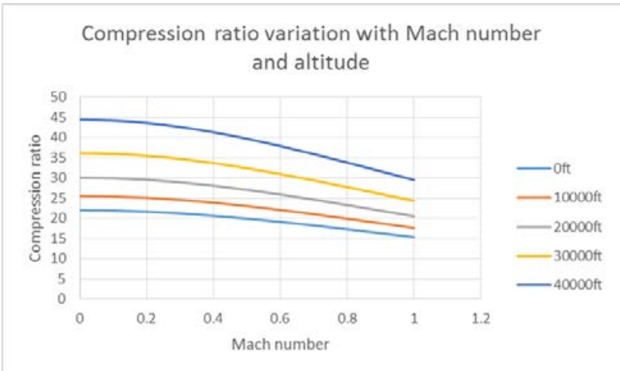
$$V = a * M \qquad a = \sqrt{k * R * T_H}$$

4/ Dynamic Pressure Ratio, as the ratio of stagnation to static pressure or the ratio of stagnation to static temperature), Fig. 12,
5/ Compressor Pressure Ratio variation with altitude, Fig. 13,
6/ Fan Pressure Ratio variation with altitude, Fig. 14,
7/ Bypass ratio, Fig. 15,
8/ Air Mass Flow Rate, on Core Flow, Fig. 16,



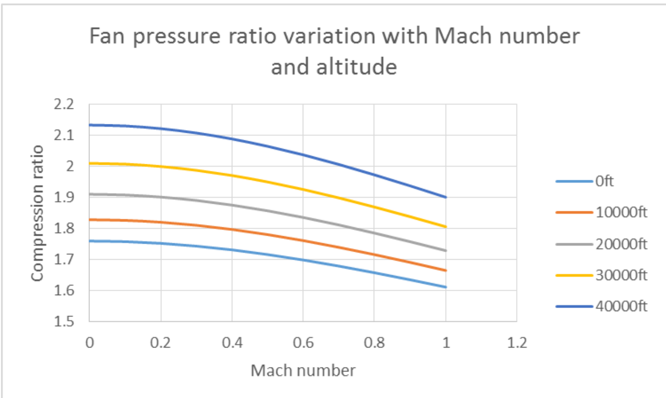
$$\pi_d^* = \frac{p_H^*}{p_H} = \left(\frac{T_H^*}{T_H}\right)^{\left(\frac{k}{k-1}\right)}$$

FIG. 12 Dynamic compression ratio variationwith Mach number



$$\pi_c^* = \left(1+\frac{T_0}{T_H}*\frac{1}{\theta(M)}*\left(\pi_{c0}^{*\left(\frac{k-1}{k}\right)}-1\right)*\bar{n}^2\right)^{\left(\frac{k}{k-1}\right)}$$

FIG. 13 Compressorpressureratio variationwith Mach number and altitude



$$\pi_v^* = \left(1+\frac{T_0}{T_H}*\frac{1}{\theta(M)}*\left(\pi_{v0}^{*\left(\frac{k-1}{k}\right)}-1\right)*\bar{n}^2\right)^{\left(\frac{k}{k-1}\right)}$$

FIG. 14 Fan pressureratio variationwith Mach numberand altitude

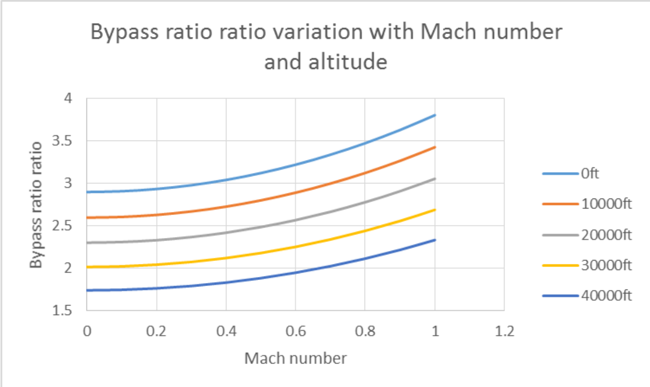


FIG. 15 Bypass ratio variationwith Mach number and altitude

$$K = \frac{\dot{M}_{a\_2}}{\dot{M}_{a\_1}}$$

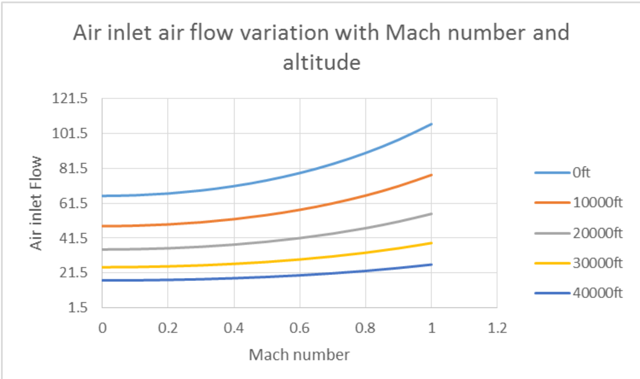


FIG. 16 Air Mass Flow Rate (on Core Flow) variationwith Mach number and altitude

$$\dot{M}_{a\_1} = \dot{M}_{a\_1_0} * \frac{\pi_c^*}{\pi_{c0}^*} \cdot \pi_d^* * \frac{p_H}{p_0}$$

Air Mass Flow Rate (on Core Flow)

$$\dot{M}_{a\_2} = \dot{M}_{a\_2_0} * \frac{\pi_v^*}{\pi_{v0}^*} \cdot \pi_d^* * \frac{p_H}{p_0}$$

Air Mass Flow Rate (on Bypass Flow)

Compressor pressure ratio variation with Mach number and altitude is determined from specific work variation at different altitudes and flight regimes in correlation with engine rotation speed.

$$l_c = l_{c0} * \overline{n}^2$$

Likewise, Fan Pressure Ratio variation with Mach number and altitude is determined from specific work variation at different altitudes and flight regimes in correlation with engine rotation speed.

$$l_v = l_{v0} * \overline{n}^2$$

8/ Overall Air Mass Flow Rate (core flow + bypass flow) variation with Mach number and altitude

$$\dot{M}_a = \dot{M}_{a\_1} + \dot{M}_{a\_2}$$

Overall Air Inlet Mass Flow Rate variation with altitude and (implicitly with) Mach number

$$\frac{\dot{M}_a}{\dot{M}_{a0}} = \frac{(\pi_c^*) * (\pi_d^*) * \left(\frac{p_H}{p_0}\right)}{(\pi_c^*)_0}$$

The accuracy of the results is strongly influenced by the Mathematical Modelingof the turbojet engine and the assumptions taken into consideration, that is the level of the approximation. The numerical accuracy depends on the numerical methods and algorithms chosen for solving numericallythe equations that define the turbojet engine's mathematical model. Only few equations can be solved analytically.

4. FINAL RESULTS AND CONCLUSIONS

The study is concluded by the results obtained from Numerical Simulations.

4.1 CONCLUSIONS - Predicted Performances at Design and Off-Design Regimes

Table 8. VIPER 632-41 Turbojet Engine PerformancePrediction at Design Regime and Off-Design Regimes

THRUST [N], Design Regime, 100% RPM

Mach	H = 0 [km]	H = 3.048 [km]	H = 6.096 [km]	H = 9.144 [km]	H = 12.192 [km]
0	17611.2274	14064.7327	11051.1503	8526.2399	6443.118
0.1	16821.365	13485.7161	10634.7039	8233.1384	6241.9055
0.2	16231.2135	13056.5907	10328.8064	8019.9201	6097.0421
0.3	15824.0499	12765.5722	10125.3306	7881.1181	6004.9565
0.4	15586.4382	12603.3288	10017.9314	7812.5238	5962.9367
0.5	15507.7917	12562.6696	10001.8323	7811.0451	5969.0406
0.6	15579.9896	12638.2715	10073.6377	7874.5832	6022.0168
0.7	15797.0244	12826.4311	10231.1645	8001.9217	6121.2360
0.8	16154.6577	13124.8272	10473.2834	8192.6246	6266.6273
0.9	16650.0655	13532.2817	10799.7624	8446.9374	6458.6183
1.0	17281.4571	14048.5086	11211.1057	8765.6874	6698.0759

TSFC [kg/Nh], Design Regime, 100% RPM

Mach	H = 0 [km]	H = 3.048 [km]	H = 6.096 [km]	H = 9.144 [km]	H = 12.192 [km]
0	0.120334	0.117176	0.114073	0.111002	0.107945
0.1	0.126436	0.122637	0.118947	0.115338	0.111785
0.2	0.132443	0.128005	0.123734	0.119594	0.115552
0.3	0.13828	0.133222	0.128387	0.123733	0.11922
0.4	0.143883	0.138237	0.132867	0.127724	0.122764
0.5	0.149203	0.143009	0.137142	0.131545	0.126167
0.6	0.154205	0.147513	0.141191	0.135177	0.129414
0.7	0.158877	0.151736	0.145004	0.138611	0.132499
0.8	0.163223	0.155679	0.148579	0.141848	0.13542
0.9	0.167264	0.159359	0.151929	0.144892	0.138182
1.0	0.171037	0.162801	0.15507	0.147759	0.140793

THRUST [N], Off-Design Regime, Ground Idling 40% RPM

Mach	H = 0 [km]	H = 3.048 [km]	H = 6.096 [km]	H = 9.144 [km]	H = 12.192 [km]
0	1859.5139	1423.3356	1060.1846	766.3173	535.4412
0.1	1698.6657	1313.2768	987.1142	719.4401	506.5386
0.2	1634.4156	1268.2958	956.9432	700.1183	494.7941
0.3	1652.9308	1280.3889	965.151	705.8745	498.9005
0.4	1741.5514	1342.2444	1007.6809	734.5646	517.7909
0.5	1891.5221	1448.7489	1081.7213	784.7569	550.8092
0.6	2098.5088	1597.4398	1186.0202	855.921	597.8124
0.7	2361.9961	1788.3028	1320.8496	948.4488	659.1985
0.8	2684.4768	2023.3728	1487.8316	1063.5906	735.8915
0.9	3070.7825	2306.3656	1689.7518	1203.3718	829.3109
1.0	3527.6048	2642.397	1930.4088	1370.521	941.343

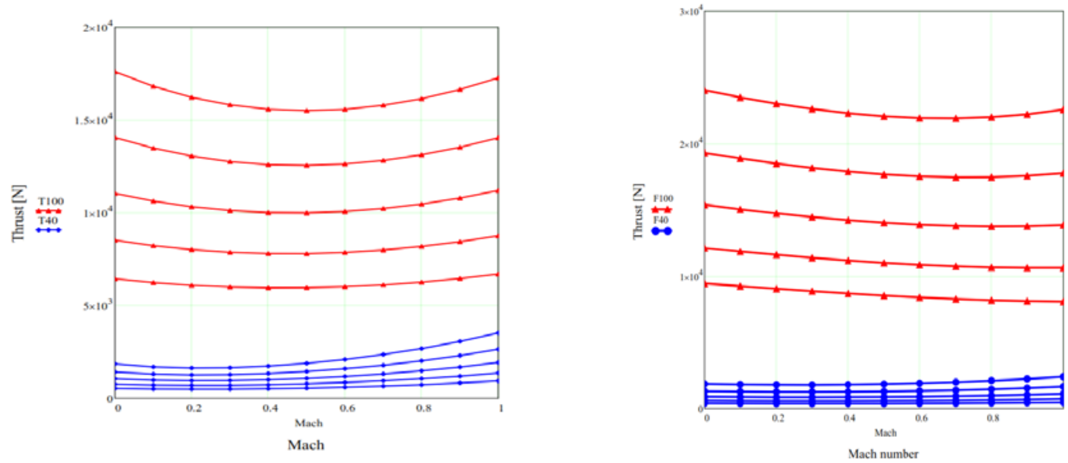
TSFC [kg/Nh], Off-Design Regime, Ground Idling 40% RPM

Mach	H = 0 [km]	H = 3.048 [km]	H = 6.096 [km]	H = 9.144 [km]	H = 12.192 [km]
0	0.326336	0.305838	0.287185	0.269906	0.253642
0.1	0.359318	0.3334	0.310237	0.289159	0.269661
0.2	0.379981	0.351267	0.325612	0.302316	0.280847
0.3	0.386662	0.358078	0.332228	0.308542	0.286569
0.4	0.381848	0.355412	0.33108	0.308454	0.287202
0.5	0.369689	0.34626	0.324305	0.30356	0.283795
0.6	0.353912	0.333543	0.314155	0.295568	0.277619
0.7	0.337086	0.319438	0.302435	0.285941	0.26983
0.8	0.320715	0.30533	0.290377	0.275744	0.261324
0.9	0.305562	0.291994	0.278731	0.265674	0.252726
1.0	0.291945	0.279806	0.267902	0.256142	0.244434

Table 9. Mixed Flows Turbofan EnginePerformancePrediction at Design Regime and Off-Design Regimes

H [km]	Mach	V [m/s]	π_d^*	π_c^*	π_v^*	$\dot{M}_{a\_1}$ [kg/s]	$\dot{M}_{a\_2}$ [kg/s]	K	$\dot{M}_a$ [kg/s]
12.192	0.8	231.7	1.5243	33.8318	1.9736	7.286	15.406	2.115	22.693
12.192	0.7	202.7	1.3871	35.9289	2.0071	7.041	14.258	2.025	21.299
9.144	0.7	212.13	1.3871	29.4177	1.8994	9.284	21.728	2.340	31.012
6.096	0.7	221.13	1.3871	24.6366	1.8120	12.034	32.085	2.667	44.120
3.038	0.7	229.78	1.3871	21.0235	1.7400	15.371	46.113	3.001	61.484
0// ISA 15[C]	0	0	1.0000	22.00	1.76	16.865	48.907	2.900	65.772
0// 24.40 [C]	0	0	1.0000	20.5214	1.7294	15.731	48.056	3.054	63.787
0// 30.56 [C]	0	0	1.0000	19.7134	1.7121	15.112	47.577	3.148	62.689

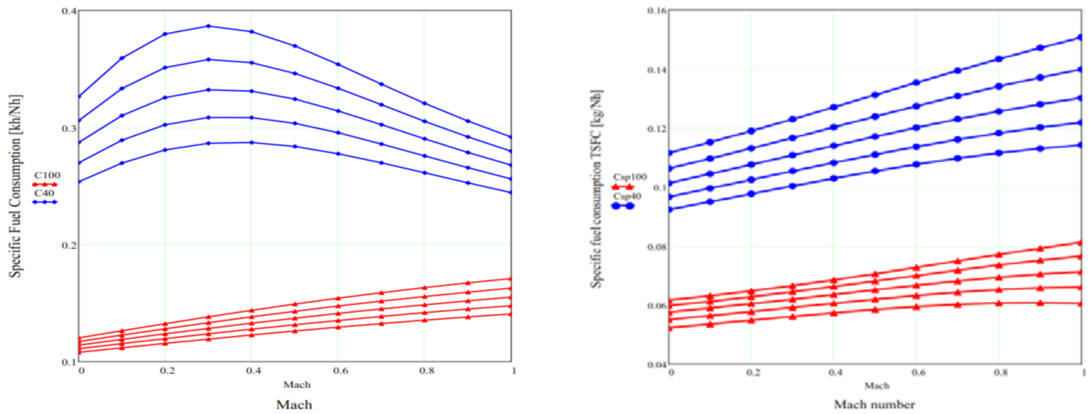
Turbojet engine provides less Thrust than the Turbofan engine at 100% RPM, while at Ground Idling 40% RPM, the Thrust increases with Mach number (Turbojet), but the variation is much more smooth (Turbofan).



Viper MK 632-41 Turbojet Engine Mixed Flows Turbofan Engine

FIG. 17 Variation of **THRUST [N]** with Mach number and altitude

Since it provides larger Thrust for all the flying regimes, not only for temporarily use of the Afterburner, the Mixeds Flows Turbofan is a better option than the Turbojet engine.



Viper MK 632-41 Turbojet Engine   Mixed Flows Turbofan Engine

FIG. 18 Variation of **Specific Fuel Consumption-TSFC [kg/Nh]**with Mach number and altitude

Turbojet engine consumes more fuel (significant larger TSFC) than the Turbofan engine when increasing the flight velocity (Mach number); this behavior is similar for 100% RPM and at Ground Idling 40% RPM. Since it consumes less fuel, i.e. reduced TSFC for all the flying regimes, the Mixeds Flows Turbofan results as improved option than the Turbojet engine.

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