# ASPECT REGARDING OF THE PRATT & WHITNEY F100 JET ENGINE PERFORMANCES

**Vasile PRISACARIU, Alexandru CIUBOTARU**
"Henri Coandă" Air Force Academy of Braşov, Romania (aerosavelli73@yahoo.com, aleczvasile@yahoo.ro)

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***Abstract:*** A jet engine is a category of propulsors that can be continuous improved, starting from concept to design and execution to management of thrust and also new approaches regarding maintenance activities. Last decades, the usage of jet engines extended into aeronautical area (UAV, UCAV) as well as into unusual ones (auto-transport, electrical generators). The article wants a review of the F-100 jet engine by exposing a performance analysis using a software tool on an equivalent model.

***Keywords:*** *jet engine, Gasturb, F-16 Fighting Falcon, F100-PW220.*

***Acronims***

| | | | |
|---|---|---|---|
| *U(C)AV* | *Unmanned (Combat) Aerial Vehicles* | *ATECG* | *Advanced Turbine Engine Gas Generator* |
| *DEEC* | *Digital Electronic Engine Control* | *LOD* | *Light-off Detector* |
| *EQ* | *Equivalent* | $V_H$, $V_h$ | *Speed* |
| $\eta$ | *Efficiency* | *T* | *Thrust* |
| $\alpha$ | *Air coefficient redundance* | *W* | *Weight* |
| $G_c$ | *Fuel flow per hour* | *Q* | *Heat quantity* |
| *S* | *Surface* | *HPC* | *High pressure compressor* |
| *HPT* | *High pressure turbine* | | |

## 1. INTRODUCTION

### 1.1. F100 general consideration.

The engine was created at the request of United States Army and United States Navy which issued a joint engine request for proposals for the F-14 Tomcat and F-15 Eagle fighters during a program called Advanced Turbine Engine Gas Generator (ATECG) whose goal was to improve thrust and weight to achieve a trust-to-weight ratio of 9. The program awarded Pratt & Whitney company with a contract to produce F100-PW-100 (USAF) and F400-PW-400 (USN) engines, [1, 2, 3], see figures 1 and 2.

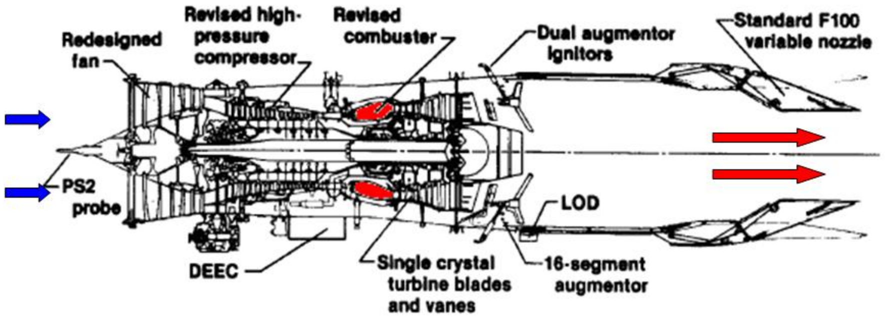


**FIG. 1** F100 jet engine diagram, [2, 3]

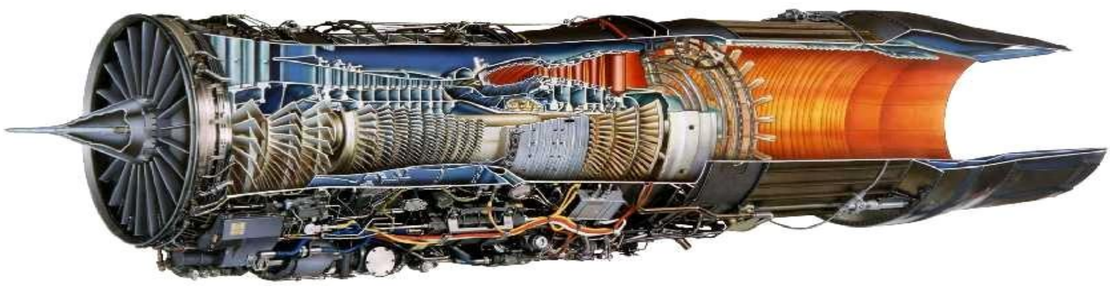

**FIG. 2** F100 jet engine [2, 3]

**1.2. F100 Versions**

The engine is built in more than 7200 pieces, in various versions, and it is currently used in 23 worldwide national air forces, the fiability record being established by the F100-PW-229, [1, 10].

*a. F100-PW-100.*

The first version is the basic of this engine. The F100-PW-100 first powered the F-15 Eagle in 1972 with a thrust of 106,4 kgf. Numerous problems were encountered in the first days of its use, including high wear, stilling and “hard” afterburner starts. The consequences of these problems caused the large jets of jet fuel to be lit by the engine exhaust resulting in high pressure waves that caused the engine to stall. These problems were solved in an alternate version of this engine, the F-100-PW-F220.

*b. F-100-PW-200.*

F100-PW-200 engine was the second version of the F100 engine. It was created seeking a way to drive unit costs down. The Alternative Fighter engine program was implemented by USAF in the 1984 and the engine contract was awarded through competition. The F-16C/D Block 30/32 was the first block of planes to use this engine, able to accept the existing engine or the General Electric F110.

*c. F100-PW-200/220E*

This engine was created due to unsatisfactory reliability, maintenance costs and service life of the F100-PW-100/200. Pratt & Whitney Company was pressured to upgrade the engine to solve these issues; the resulting engine was the F100-PW-220. The engine eliminates stall-stagnations and augmenter instability as well as doubling the time between depot overhauls. Reliability and maintenance costs were drastically improved and the engine incorporates a digital electronic engine control (DEEC). This engine was released in 1986 and was compatible on either F-15 or F-16. The “220E” name is given to engines which have been upgraded from series 100 or 200 to 220 thus becoming equivalent to 220 specifications.

*d. F100-PW-229*

The 229 has a thrust of 79,18 kN (dry thrust) and 129,7 kN with afterburner. The late F-16 Fighting Falcon (see figure 3a) and the F-15E Strike Eagle (see figure 3b) are currently powered by this engine. The current production of F100-PW-229 Engine Enhancement package incorporates modern turbine materials, aerodynamics compressor, electronic controls and cooling management [4].



(a)



(b)

**FIG. 3** The applications F100 engine, a. F15E Strike Eagle, b.F16 Fighting Falcon [5, 6]

### 1.3. Jet engine description.

The F100 jet engine is a two-spool (mixed flow) low by-pass engine, equipped with a high degree compression axial compressor, a post-combustion chamber and a variable geometry nozzle. In table 1 we present the most significant characteristics and performances of the F100 engine family.

*Table1. Characteristics and performances*

| | F100-PW-220 | F100-PW-229 |
|---|---|---|
| Type | Afterburning turbofan | |
| Length | 4900 mm | |
| Diameter | 880 mm inlet, 1180 mm max. | |
| Dry weight | 1,467 kg | 1,700 kg |
| Maximum Thrust | 64,9 / 105,7 kN afterburner | 79,18 / 129,7 kN afterburner |
| Pressure ratio | 25:1 | 32:1 |
| Specific consumption | Military thrust (0.73lb/(lbfxh)) | Military thrust (0.76lb/(lbfxh))<br>Full afterburner: 1.94lb/(lbfxh) |
| Thrust-to-weigh ratio | 7.4:1 | 7.8:1 |

## 2. THEORETICAL ASPECTS

### 2.1. Jet engine main functioning parameters.

Main parameters define the operating modes and implicitly the physical and chemical configuration of the flow filed into the jet engine sections, which are: engine rotation (rot/min), specific thrust ($T_{sp}$), the exit flow temperature ($T_3^*$), the engine thrust and specific fuel consumption.

The functioning conditions can be: cruising (constant rotation speed, constant fuel flow, constant speed flight, invariable engine interior geometry), transitory (fuel flow, revolution, flight speed, altitude variations in time) and unstable (functioning characteristics constant, but in time, the fuel flow into the engine is unstationary)

### 2.2.Parameters of the jet engines

Jet engine are defined by a series of specific parameters that give marks regarding global performances of them, [9, 12, 14].

-specific thrust:

$$T_{sp} = \frac{T}{W} \qquad \frac{daN \cdot s}{kg} \tag{1}$$

- specific fuel flow:

$$C_{sp} = \frac{G_c}{F_t} \qquad \frac{kg}{daN \cdot h} \tag{2}$$

-specific frontal thrust:

$$F_{spf} = \frac{F_t}{S_{\max}} \quad \frac{daN}{m^2} \tag{3}$$

-specific engine weight:

$$W_{sp} = \frac{W_e}{T_t} \quad \frac{kg}{daN} \tag{4}$$

**2.3. Jet engines efficiency**

Jet engine mainly converts chemical energy into movement mechanical work in mid-air [9].

-global efficiency (the ideal model of engine transformations):

$$\eta_g = \frac{T_{sp} \cdot V}{Q_o} \tag{5}$$

- thermical eficiency of the real engine:

$$\eta_c = \frac{\left(c_5^2 - V_H^2\right)}{2 \cdot Q_o} \tag{6}$$

where $c_5$-gas exit speed (reactiv nozzle).

Thermodynamic efficiency of the real cycle is $\eta_t$=0,25 ÷0,4 because of the losses of energy (incomplete burn), mechanical and thermal losses into the environment.

-flight efficiency:

$$\eta_F = \frac{T_{sp} \cdot V_h}{\frac{1}{2} \cdot \left( \frac{1 + \alpha \cdot L_0}{\alpha \cdot L_0} \cdot c_5^2 - V_H^2 \right)} \tag{7}$$

where $V_h \neq 0$, α the air excess coefficient and $L_0$ the theorethical quantity of air required for a complete burn.

## 3. PW F100 JET ENGINE SOFTWARE ANALYSIS

**3.1. Software description.**

GasTurb is an engineering software developed by Dr. Joachim Kurzke, firstly in 1991 and the optimization and development of the program continues to the present and future. The latest version of this program and the one we used is GasTurb 12. This software deals with interpretation of engine test results and diagnosis of operational problems, providing control system designers with a simulation of the engine model, providing operators, airframe manufacturers and power station designers with mathematical models and a lot of other functions.

**3.2. The case study.**

For the case study I chose an F-100-EQ two-spool turbofan (mixed flow) low by-pass engine place in the same category as F-100 engine that equips F-16 Fighting Falcon. The *"basic thermodynamics–cycle design–design point"* analysis has the main parameters highlighted in table 2 in base configuration of the software tool, where we consider zero pressure losses, the exclusion of the turbine to be cooled [7] and specific parameters of the engine, [11].

*Table2. Initial main condition*

| Condition | Value | Condition | Value |
|---|---|---|---|
| Speed | 0 km/h | Altitude | 0 m |
| Ext. temperature | 288 K | Ext. pressure | 101325 kPa |
| Intake pressure ratio | 0,99 | Burner exit temperature | 1700 K |
| Mixed efficiency | 0,5 | Burner pressure ratio | 0,99 |
| Design nozzle petal | $25^0$ | Mass flow input | 111,5 kg/s |
| HPC efficiency | 0,88 | HPT efficiency | 0,87 |
| Afterburner | no | | |

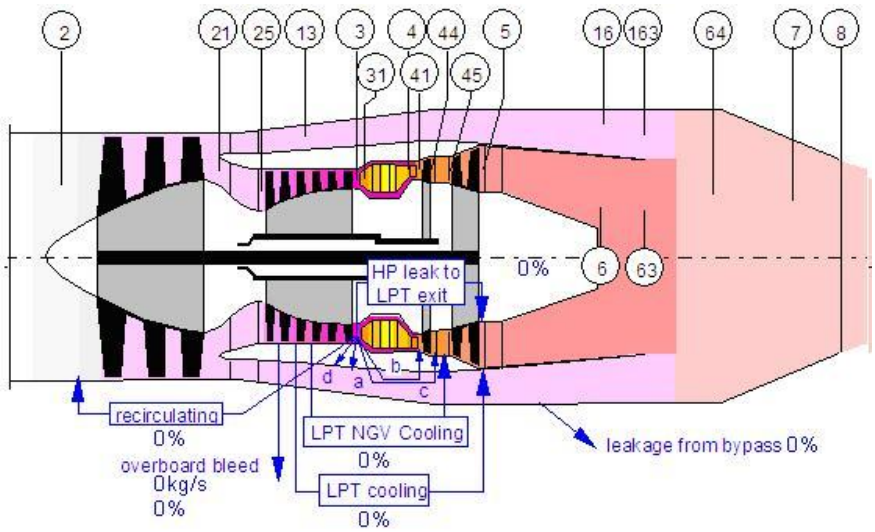


**FIG. 4** Total temperature and velocity in jet engine stations, [7]

For Figure 4 jet engine stations: 2-first compressor inlet, 21-inner stream fan exit, 25-high-pressure compressor inlet, 13-outer stream fan exit, 3-last compressor exit, cold side heat exchanger inlet, 31-combustor (burner) inlet, 4-combustor (burner) exit, 41-first turbine stator exit = rotor inlet, 44-high-pressure turbine exit after addition of cooling air, 45-low-pressure turbine inlet, 5-low-pressure turbine exit after addition of cooling air, 6-jet pipe inlet, reheat entry for turbojet, hot side heat, exchanger inlet,16-bypass exit, 63-hot side mixing plane, 163-cold side mixing plane, 64-Mixed flow, reheat entry, 7-reheat exit, hot side heat exchanger exit, 8-nozzle exit, [7].

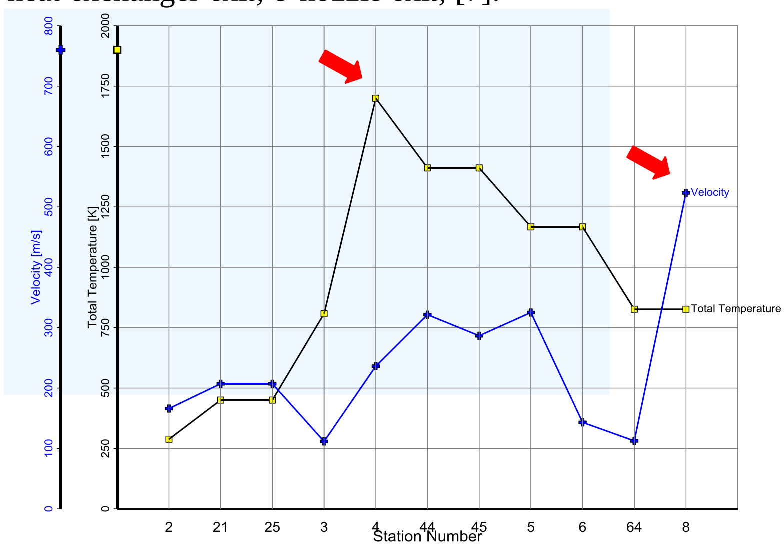


**FIG. 5** Total temperature according to velocity in jet engine stations

In figure 5, there can be observed the speed and temperature variations in the engine sections, an accentuated growth of temperature in the burning chamber (sections 3-4) within reaching a maximum of 1700k (section 4) and a obvious speed variation from 100 m/s (section 2) to approximately 1300 m/s (section 8). Also in figure 6 is revealed quasi-identical variation of the entropy according to the total temperature in the engine sections, and the differences of those parameters from section 2 to 8.

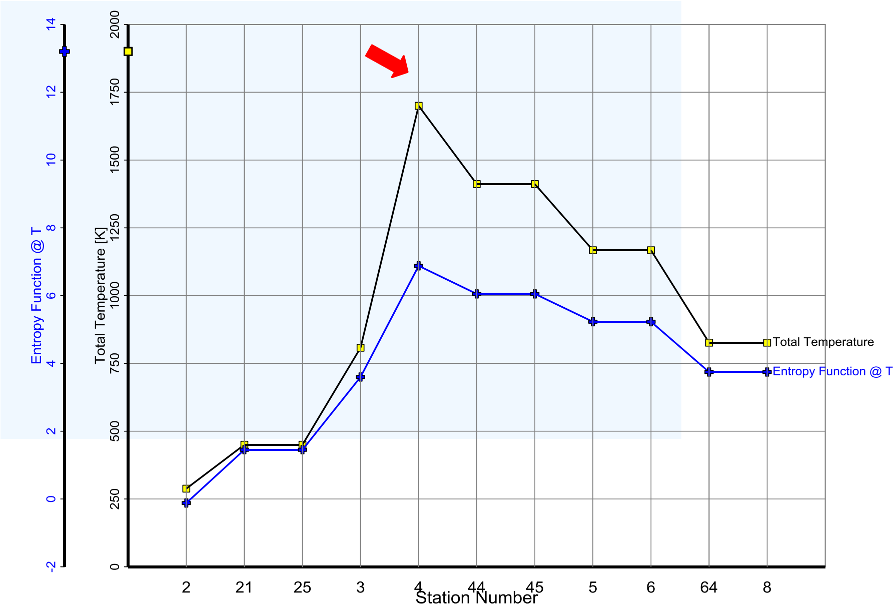


**FIG. 6** Entropy function according to total temperature in jet engine stations

In Figure 7 can be observed the variation of the density according to total pressure into the engine sections. To note the values of the 2 parameters in the burning chamber (sections 3-4).

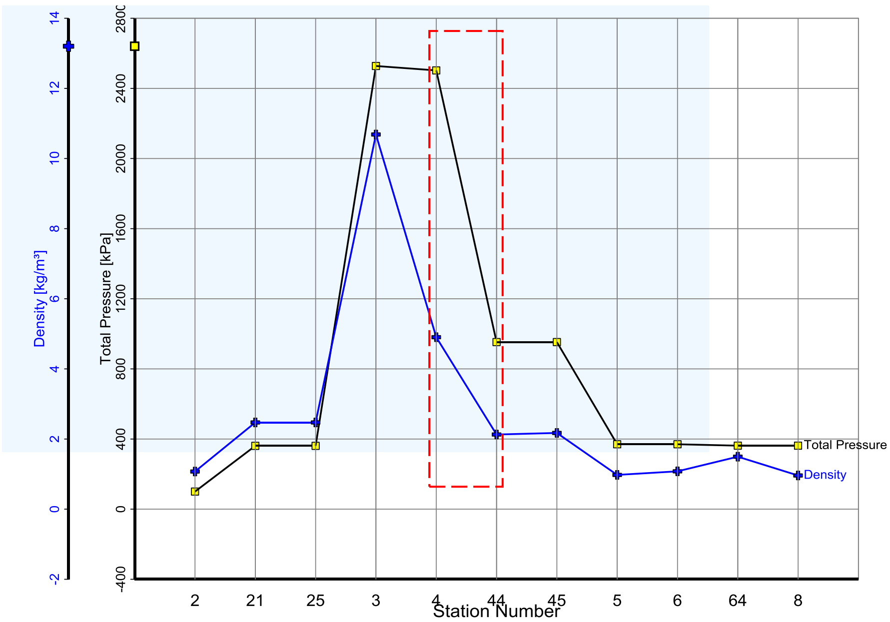


**FIG. 7** Density according to total pressure in jet engine stations

In Figure 8 we can observe the limits of the variation of the entropy according to the jet engine functioning temperature gap, and Figure 9 shows the variation of pressure according to the gas volume.

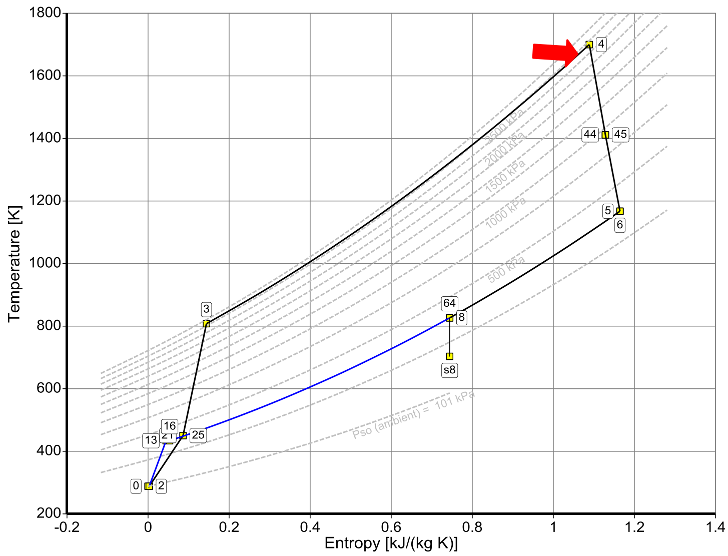


**FIG. 8** Entropy according to total temperature

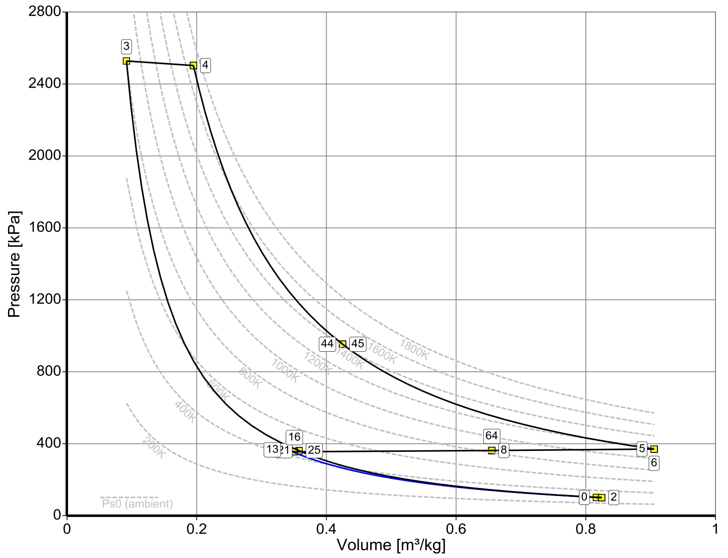


**FIG. 9** Pressure according to volume

From the study case resulted a maximum thrust of 78,73kN, which can be compared to the data from the specialty literature (79,18 kN), [11].

## 4. CONCLUSIONS

Propulsion systems of the aircrafts were and are continuously enhanced and the numerical and simulation methods regarding the optimization of the performances complete the experimental researches that can confirm or not the researchers's previsions.

Software tools used for numerical simulation of propulsion systems performance can approach the aspects of global design goals, optimization options identification, operational problem diagnosis, performance assessment, and interactive teaching methods in the field of propulsion systems.

GasTurb can also be used for teaching gas turbine thermodynamics through graphically exported data of parametric studies that can reveal real figures about how thermal efficiency depends on the pressure ratio and the exit temperature of the combustion chamber.

GasTurb provides assistance to users who need to examine the measured data on a gas turbine in service or in the test stage to confirm the expected performance by creating a precise simulation of a real motor based on typically limited information.

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