Estimation and Calculus of Turbojet Performances with Optimal Turbine Blades Cooling

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Abstract

The temperature augmentation of the turbine inlet gas will always produce an augmentation of thrust, thus the improving of overall performances of the turbojet. This augmentation will benefit the performance, but this effect has drawbacks because of the produced effects on the turbine blades such as the thermal fatigue, the corrosion and also the creep.

These problems act and influence on the thermal and mechanical characteristics of the material, so the factors of security and cost are affected accordingly. Under these conditions, the turbine blades must be cooled to maintain their integrity and achieve their maximum life period.

The principal objective of this work is to develop a data processing application able to calculate the turbojet performances, as well as the calculation of turbine blades cooling.

The developed application makes the calculation of the turbine blades cooling to different altitudes, and has certain advantages, such as: the possibility to have detailed results, the capacity to work out a report, the total absence of intermediate calculations appearance and a total elimination of the curves and graphs use to get the values of each simulation.

Keywords: Engine Performances, Thermodynamic Turbojet Cycle, Turbine Blades Cooling.

1. INTRODUCTION

During the development of aviation, engines take an important interest for the increase of flight performances (thrust, power, and engine performances). For further increase of the efficiency, the manufacturers are strongly interested by the improvement of the performances of the aircraft gas turbine in particular the turbojets [1, 2].

The aviation industry has made significant progress by reducing the consumption of kerosene and by limiting the emissions of hydrocarbons and carbon monoxide. These improvements were mainly obtained by improving combustion in the aircraft engine [3-7, 19].

The turbine blades can thus be exposed to very high temperatures of combustion gases, close to 1500°C at peak, the temperatures reached at the end of the combustion cannot be supported by used materials (order of use of 1100°C). It is consequently necessary to cool them [1, 8].

The augmentation of the temperature of the turbine inlet gas will always produce an augmentation of thrust, thus the improving of overall performances of the turbojet. This augmentation will benefit the performance, but this effect has drawbacks because of the effects produced on the blades of the turbine, such as the thermal fatigue, the corrosion and also the creep caused by the centrifugal force caused by the rotation of elements.

These problems influence on the thermal and mechanical characteristics of the material, so the factors of security and cost are affected accordingly [9-11].

Under these conditions, the turbine blades must be cooled to maintain their integrity and achieve their maximum life period [11, 12].

The cooling system is needed to increase the reliability of the turbine and other components, the cooling by the air was used (the air comes from the top floor of high-pressure compressor, it is fed into the turbine blades by their roots), this system is based on the use of the principle of thermal convection [13, 14].

Using the heat transfer equations and the thermodynamic turbojet cycle formulas [15-17], cooling of turbine blades is studied by understanding what happens at the beginning. Especially, how made the heat exchange between the fresh air and the wall of dawn hot? And how the cool temperature varies depending on other settings?

Experimental activities on real aeronautical turbines can be very complex and expensive, so, the use of parts of real engines or small-size turbojets can be very useful for research activities.

In recent years, numerical studies and simulations have made significant advancements in field of development of software used to more understanding and improvement the engine design.

This approach provides the basic needs for the two key objectives of engine design: performance evaluation and emission optimization [18-21].

A data processing application was developed to calculate the performances of the turbojet as well as the calculation of cooling, i.e. the values of the temperatures of the blades and the fluid used to have good working conditions in order to obtain a good utilization with a long lifetime of components of this turbojet.

2. PROBLEM DESCRIPTION

The turbojet consists of several main components, presented in the following order from front to back (see figure 1): the fan, the compressor, the combustor, the turbines and finally the nozzle. When air passes through these elements, pressure, temperature and speed vary. These variations produce forces whose resultant is the propelling force of the aircraft [12, 13].

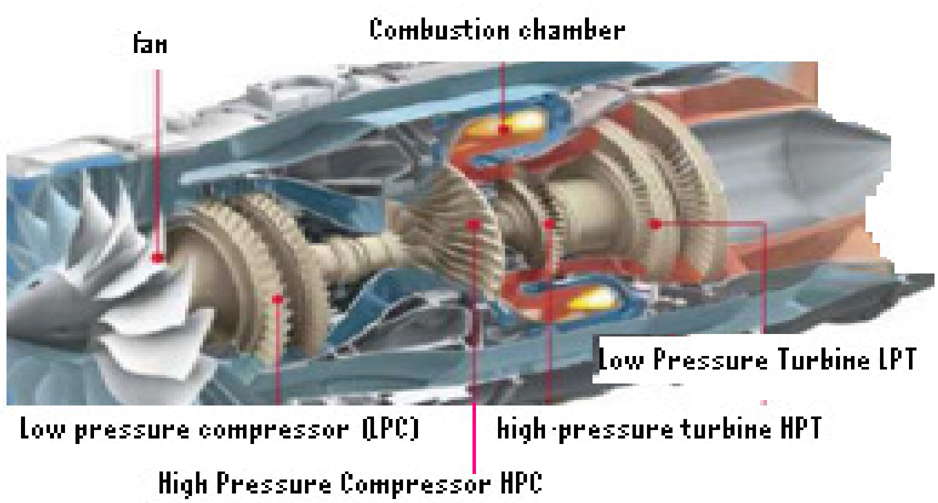

FIGURE 1: Turbojet Components.

In designing a blade cooled of air engine, the cooling system must meet design criteria that are dictated by three constraints which are: creep, thermal fatigue and oxidation and corrosion.

The three constraints are dependent on temperature (or the temperature difference) although other factors such as the geometry of various components.

The requirements to have a satisfactory life of turbine blades are:

-The higher temperature that may reach the threshold should be lower than the limit of the temperature of corrosion.

-The average temperature of the blade must be low enough to achieve the life period of creep under the level of operational centrifugal load.

-The temperature differences of blade in cooled section under the conditions of transitory and permanent states must be as low as possible to avoid thermal fatigue.

The performances of aircraft engine are described through two important parameters: the specific thrust (ST) and the thrust specific fuel consumption (TSFC).

To dimensioning engine system, it is important to find the best compromise between maximal specific push and minimal specific consumption. For that, two characteristic variables of the engine must be giving:

- The turbine inlet temperature (TIT) which represents the temperature of combustion gases at the entry of the high pressure turbine.

- The compressor pressure ratio (CPR).

The performances improvement of engine thus passes by the increase in the temperature at the turbine entry and the compression ratio. The principal objective is to find a point of optimal use making it possible to maintain the turbine blades at an acceptable maximum temperature and to limit the local variations in temperatures in order to guarantee their integrity during all the lifespan of the engine.

3. TURBOJET CYCLE

The locations of stations at which velocities and thermodynamic states were computed are shown in Figure 2.

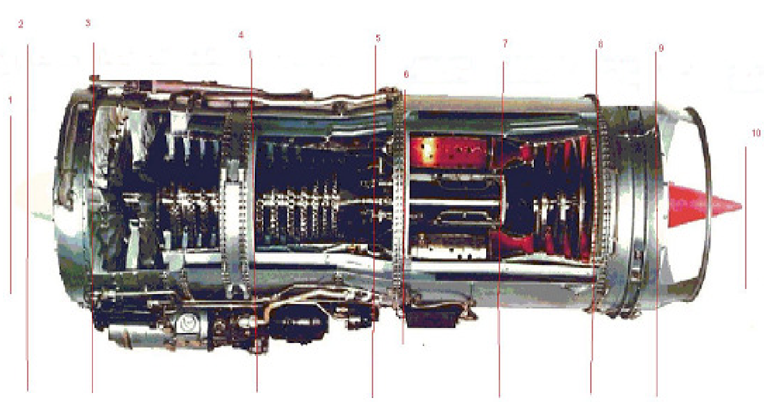

FIGURE 2: Stations of Turbojet Cycle.

1 to 2: Air inlet or diffuser.

2 to 3: Fan, which gives a compression beforehand to air and then divides the airflow into two flows, the primary airflow through the reactor and the secondary airflow through the annular gap between the hull and the stators of the low pressure turbine.

3 to 4: Low pressure compressor (LPC), in which the primary flow undergoes a first adiabatic compression.

4 to 5: High pressure compressor (HPC), in which the compressed air being partially penetrates and reaches the pressure and temperature of ignition.

5 to 6: Diffuser upstream to the combustion chamber.

6 to 7: Combustion chamber, in which the flow acquires a quantity of energy delivered by the combustion, the temperature increases dramatically as the pressure is almost constant.

7 to 8: high-pressure turbine (HPT), in which gases leaving the combustion chamber with raised pressure and temperature, undergo a first stage of adiabatic relaxation, which creates a fall of high pressure, recovered in a kinetic energy.

8 to 9: Low pressure turbine (LPT), who is the continuation of the relaxation of the gas to escape.

9 to 10: Nozzle, in which the pressure energy is converted into kinetic energy. The exhaust gases continue to relax until the atmospheric pressure.

4. PROGRAM DESCRIPTION

The main objective of this work is to realize a data processing application that allows calculating the turbojet performances by calculus and optimizing of the cooling in the “high pressure turbine” blades, for this, developed application was decomposed into two parts.

The first part focuses on performance calculations for a turbojet. So, to perform calculations, turbojet was divided on ten different stations (starting with the first station proposed by the input of engine and reach the last one that is the end of engine, see figure 2).

In each of these ten stations, aerodynamic and thermodynamic characteristics of the airflow of turbojet were determined, such as for example the static temperature, the total temperature, the static pressure, the total pressure, the velocity of flow and the Mach number, etc....

Starting by introducing the characteristics of ambient air, and using the equations of the standard atmosphere, the parameters of the original station can be calculated and subsequently progression through the various stations can be obtained by using various equations of thermodynamics.

At the end of this first part, the following results were obtained:

- Have calculated all the characteristics and all the parameters of air through the various stations of the turbojet.

- Have calculated the push, the consumption and other parameters.

- Extract certain data such as: static and total temperature, static pressure at the exit of the ‘high pressure compressor’ and the static and total temperature, static pressure at the exit of the combustion chamber, which can used later in the calculation of cooling.

In the second part, the cooling phenomenon was treated on the basis of the principle of heat transfer by convection as a base of operations. Focusing especially on the hot part of the turbojet where the problem is practically applied (in the entrance of the station of the high pressure turbine).

The developed code is able to calculate temperature of the turbine blades and the air passed in order to give estimated temperatures for proper functioning of turbojet. But the calculation procedure is not really easy because several problems of different order (physical, mathematical and programming) are encountered.

The first problem is the estimate of ideal temperature range of the high pressure turbine, (knowing that the material used in the construction of blades made of nickel alloy), why we must always work on security margin given by the manufacturer to avoid the appearance of different hazards.

Secondly, it is necessary to recall that it is not possible that the blades work with temperatures above the static temperature of the combustion chamber exit (T7), or at temperatures below the static temperature leaving the high pressure compressor (T5). So initially, the temperature of the turbine blades walls must be close to T5 and the temperature of gas leaving the combustion chamber is virtually the same as T7, so the value of temperature cooling must be between T5 and T7.

To reduce the number of iterations, Déchotomie technique was used, that allows to decompose this interval into two parts, and to limit the calculations on half of this interval. So for initial values estimation, the average value (T5 + T7) / 2 was taking as the minimum temperature of wall blades (Tp), and the value of T7 as the maximum temperature of gas in the turbine (Tf).

The second problem is the calculation of various parameters (generally these physical parameters can be funded in graphs and curves). In this work, the values from curves are replaced with those calculated from empirical equations.

Using real data considered by the manufacturer, such as length, width and thickness of the blade, the temperature of the wall (TP1) and fluid (Tf1) are calculated. Subsequently, the code compares these values with those previously estimated temperatures (Tp and Tf).

After several iterations, which calculate each time Tf1 and Tp1 and compare them with those of Tp and Tf estimated, the following conditions must be satisfied:

-The estimated temperature of the wall must be less than that calculated (Tp <Tp1).

-The estimated temperature of the fluid is greater than that calculated (Tf> Tf1).

Users need to redo the work until the verification of these conditions. The values of Tp and Tf corresponding at values of functioning can be get, i.e. values where the blades were cooled and the pressure was up.

5. APPLICATION EXAMPLE

In this section, case study of JT8-D15 turbojet was presented.

The software part was developed by Delphi language. This application gives several advantages to user such as:

• Ease in data entry.

• Possibility of re-calculations.
• Viewing the held results.

• Possibility to have detailed results.

• Ability to prepare a report on a simulation with an opportunity to record and print.

•Total absence of the appearing intermediate calculations (only animated interfaces can see), and complete elimination of the use of curves and graphs to derive values.

In what follows, application example is showing where the principal steps are presented.

Stating by the introduction of flight data (figure 3), several results can carried out after the code run (figures 4, 5).

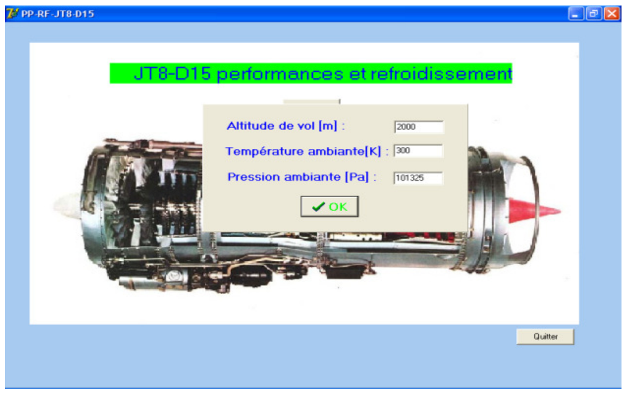

FIGURE 3: Introduction of Flight Data.

This is the main page of the program, to continue running the application, flight data such as (altitude, temperature and ambient pressure) must be input.

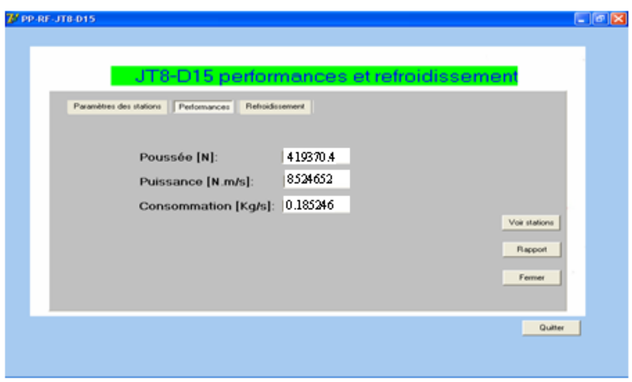

FIGURE 4: Turbojet Parameters.

Important flight performances (thrust, power, and engine performances) can be displayed. Also, attached values to various turbojet sections can be detailed (figure 5).

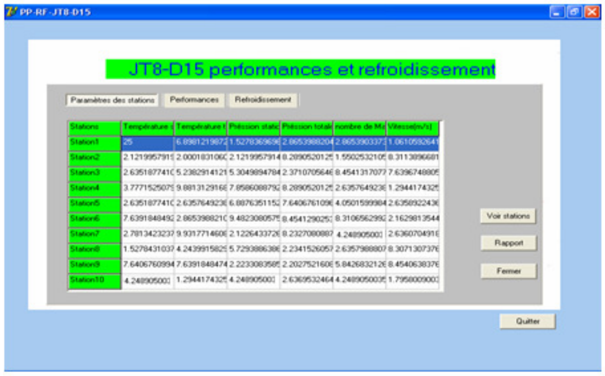

FIGURE 5: Performances at Different Stations.

The performance of the turbojet can be expressed as a function of various parameters (compressor pressure ratio, turbine inlet temperature, burner outlet temperature and the efficiencies of various components).

The values of Tp and Tf corresponding at values of functioning can be gated (figure 6).

FIGURE 6: Calculation of Cooling.

After several executions carried out by changing the setting of altitude (other parameters such as pressure, temperature and density were not taken into account because they also depend upon the altitude).

The obtained values were reported on graphs that give an interesting analysis of the various parameters on the performance of the turbojet.

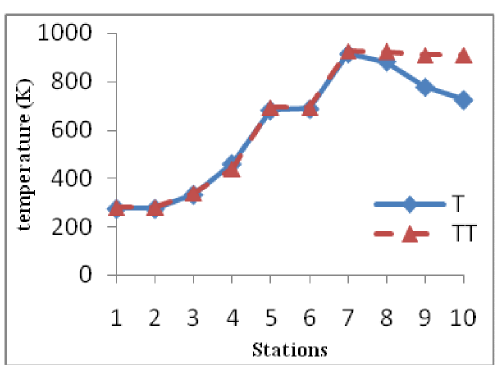

FIGURE 7: Temperature Evolution (Z=4000 m).

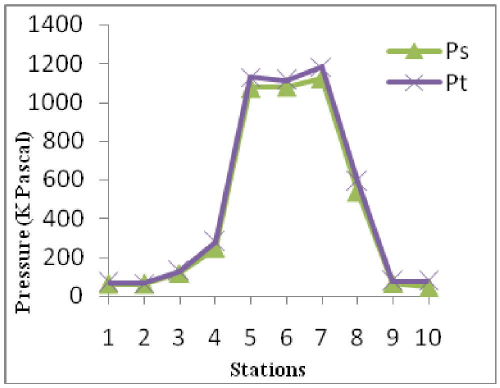

FIGURE 8: Pressure Evolution (Z=4000 m).

- In different applications, the static temperature T (and/ or total temperature TT) increases from the air inlet to the exit of the combustion chamber due to compression in compressors, and combustion in the combustion chamber, and thereafter it will be reduced due to the easing of turbines (figure 7). The same variation of the static pressure PS (and/ or total pressure PT) in the turbojet stations can be observed (figure 8), and the static pressure at the nozzle exit (station 10) is equal to ambient pressure, i.e. the nozzle is correctly expanded.

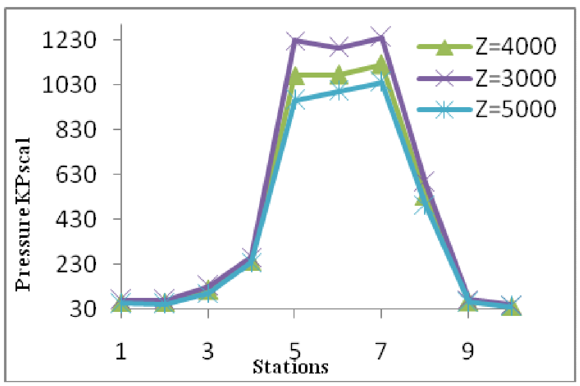

FIGURE 9: Pressure Evolution at Various Altitudes.

- The static pressure (and/ or the total pressure) decreased at the entrance of turbojet depending on the altitude, which confirms the principles of the standard atmosphere.

Altitude	Thrust ST (N)	TSFC
3000	542865	0,140
4000	669332	0,114
5000	797672	0,095

TABLE 1: Performances at Various Altitudes

- According to our calculations, the total thrust increases and the specific fuel consumption decreases whenever the altitude increases (table 1). This phenomenon is explained by the reduced air resistance as a function of altitude (i.e. that the increase in altitude causes a decrease in air resistance, implies that the consumption rate is decreased).

An optimal turbine blades cooling requires:

1. The precise determination of physical parameters (temperature, engine work conditions, pressure, flight data).

2. The perfect understanding of the parameters influence on cooling operation (material properties, cooling system, thermodynamic cycle).

The obtained values and the results drawn from the analysis show a very good agreement with those presented in different papers and technical reports [22, 23].

6. CONCLUSION

For a good exploitation of turbojet, certain requirements of various kinds (mechanical, thermal, aerodynamic, and thermodynamic) must be having, allows these requirements, this one from the increase from pushed caused by the increase in the temperature, in the exit of the combustion chamber, is chosen.

Therefore, the high temperatures at the exit of the combustion chamber are necessary to meet such a requirement, but these temperatures have drawbacks due to the effects produced on the turbine blades, such as the thermal fatigue, the corrosion, and also the creep caused by the centrifugal force caused by rotation of the other elements.

These problems influence the thermal and mechanical characteristics of material.

Under these conditions, the turbine blades must be cooled to keep their integrity and to reach one lifespan maximum.

Following a detailed description of phenomenon of cooling, as well as the presentation of the equations allowing the calculation of various performances, a data-processing code was developed.

The code execution enables to get the following results: the total and static pressures, static and total temperatures have decreased, the thrust has increased and the specific consumption of fuel has decreased whenever the altitude increases.

For the margin of cooling, it does not depend on the altitude, but it depends on the operating conditions of engine.

The number of iterations decreases with increasing altitude.

At the absence of experimental data, suggested thoughts can be proposed to encourage further works to focus research on the relationship of altitude and its influence on the blades cooling in order to get the best balance between the energy and constructive aspect of the turbojet.

The aim of this work was to obtain detailed information on the thermodynamic cycle and the performance of the engine in order to use it in future research activities on the basis of the benefits of the numerical simulations.

To arrive at good performances, parallel research and recent studies were needed in areas such as in aerodynamics, aerothermics, acoustics, combustion process, mechanics, metallurgy and manufacturing, in order to get a best engine design.

7. ACKNOWLEDGEMENT

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