Review Paper of Adaptive Work Performance Analysis of Turbojet Engines

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ABSTRACT- The review paper describes major designs of adaptive jet engines as well as their structural and operational advantages. Particular attention paid to a double-rotor engine designed by Pratt & Whitney, where a portion of air is bled from downstream of the compressor and then supplied to the area downstream the turbine when the engine is operated at its maximum performance (turbine bypass engine).Actual thermodynamic cycles of such engines and energy balance of flows. It was shown that real working cycles of these engines represent figures with variable surface areas, which is the reason for the second name of these units – engines with variable thermodynamic cycle. Engine parameters were measured in order to facilitate the recognition of incipient engine difficulties. In addition, a successful effort was made to operate the engines satisfactorily when they were severely damaged. The analysis has been conducted separately for internal and external channel. The sensitivity analysis for the working cycle makes it possible to select parameters that are potentially controllable and adjustable. To sum up the foregoing deliberations one has to state that operation of turbojet adaptive engines is the topic that needs much more investigation. Even the design solution of the engine itself, although being really exciting and promising, is troublesome in the aspects of the design and process engineering, and will lead to a series of operation and maintenance problems.

Keywords -Parameters of the engine air, sensitivity of the work cycle, adaptation engine

INTRODUCTION

The turbojet is an engine, as shown in fig. 1 usually used in aircraft. It consists of a gas turbine with a propelling nozzle. The compressed air from the compressor is heated by the fuel in the combustion chamber and then allowed to expand through the turbine.

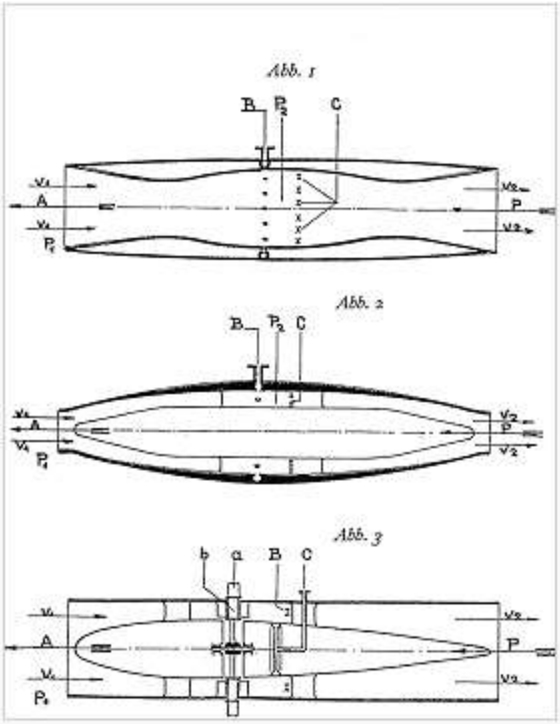

Fig. 1 Turbojet engine

Turbojets have been replaced in slower aircraft by turboprops which use less fuel. At higher speeds, where the propeller is no longer efficient, they have been replaced by turbofans. The turbofan is quieter and uses less fuel than the turbojet. Turbojets are still common in medium range cruise missiles, due to their high exhaust speed, small frontal area, and relative simplicity.

One of the most innovative and original direction of research is devoted to designs of so called turbine adaptive engines (also referred to in literature sources as engines ‘with variable thermodynamic cycle’). The basic aim of such developments is to fill the existing gap between the single-flow and double-flow engines.

The jet engine is only efficient at high vehicle speeds, which limits their usefulness apart from aircraft. Turbojet engines have been used in isolated cases to power vehicles other than aircraft, typically for attempts on land speed records. Where vehicles are 'turbine powered' this is more commonly by use of a turbo shaft engine, a development of the gas turbine engine where an additional turbine is used to drive a rotating output shaft. These are common in helicopters and hovercraft. Turbojets have also been used experimentally to clear snow from switches in rail yards.

The common use of turbine jet engines as basic drive units for both military and civil aircrafts as well as tremendous increase of demands to cost-effectiveness, noise and emission of toxic pollutants has led to drawing up of new research directions for their further development.

GAS TURBINES IN AIRCRAFT - JET ENGINES

Although the analysis of the jet engine is similar to that of the gas turbine, the configuration and design of jet engines differ significantly from those of most stationary gas turbines. The criteria of light weight and small volume, mentioned earlier, apply here as well. To this we can add the necessity of small frontal area to minimize the aerodynamic drag of the engine, the importance of admitting air into the engine as efficiently (with as little stagnation pressure loss) as possible, and the efficient conversion of high-temperature turbine exit gas to a high-velocity nozzle exhaust. The resulting configuration is shown schematically in Figure 2.

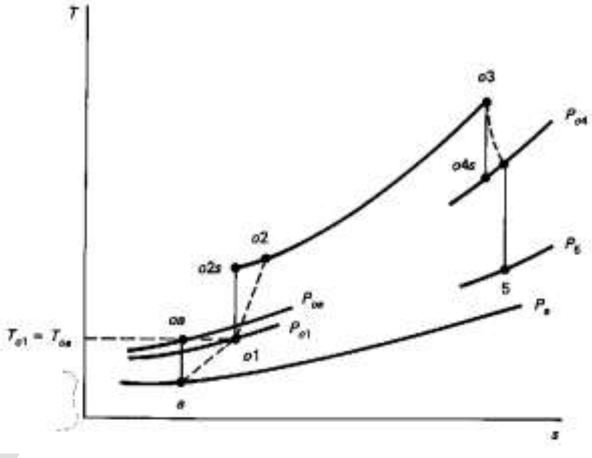

Fig.2 Jet engine notation and temperature entropy Diagram.

In early turbojet engines: solid blades the maximum admissible temperature was directly related to improvement of structural materials (*Tmax* ~ 1100 °C)

From 1960-70: development of early air-cooled turbine blades

- Hollow blades
- Internal cooling of blades (casting using the ‘lost wax’ technique)

JET ENGINE PERFORMANCE

It is seen that engine thrust is proportional to the mass flow rate through the engine and to the excess of the jet velocity over the flight velocity. The specific thrust of an engine is defined as the ratio of the engine thrust to its mass flow rate. From Equation below equation:

The specific thrust is

$$F/m = (V_5 - V_a) + (p_5 - p_a)A_5/m$$

Because the engine mass flow rate is proportional to its exit area, *A*5/*m* depends only on design nozzle exit conditions. As a consequence, *F*/*m* is independent of mass flow rate and depends only on flight velocity and altitude. Assigning an engine *design thrust* then determines the required engine-mass flow rate and nozzle exit area and thus the engine diameter. Thus the *specific thrust*, *F*/*m*, is an important engine design parameter for scaling engine size with required thrust at given flight conditions.

Another important engine design parameter is the *thrust specific fuel consumption*, TSFC, the ratio of the mass rate of fuel consumption to the engine thrust

$$\mathrm{TSFC} = m_f/F$$

ENERGY BALANCE

Real working cycles of these engines represent figures with variable surface areas, which are the reason for the second name of these units – engines with variable thermodynamic cycle. Working cycles for adaptive engines of VCE or VSCE types are typical cycles of a double flow engine, where the working area is split between bypass channels, depending on the aircraft flight conditions and operation range of the engine.

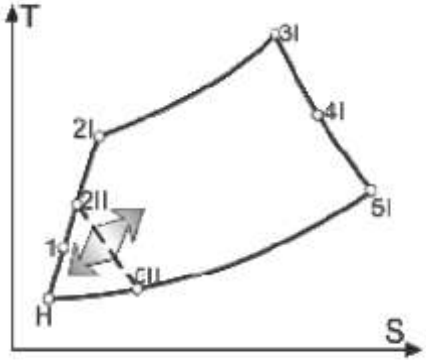

Fig. 3 Real cycle of a turbojet adaptive engine

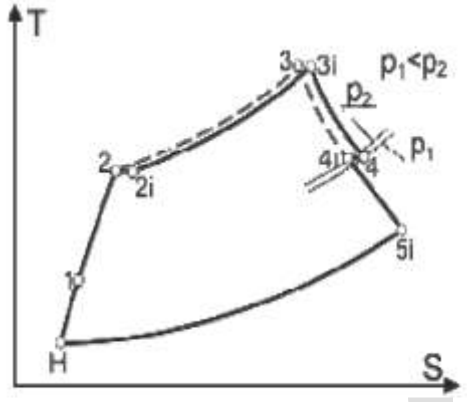

Fig. 4 Real cycle of a turbojet engine of the 'bypass' type

The working cycle of the 'bypass' engine is a typical cycle of a single-flow engine with variable area of the corresponding thermal cycle. The curve shape depends on the amount of air that is bled from downstream of the compressor and fed downstream the turbine (Fig. 4).

SENSITIVITY OF THE WORK CYCLE

The sensitivity analysis of a mathematic model is understood as estimation of increments exercised by variables of the model caused by variations of its parameters. Increments of variables are usually evaluated by differential approximations.

The sensitivity analysis for the work cycle makes it possible to select parameters that are potentially controllable and adjustable. In addition, sensitivity of the work cycle serves as the measure how individual design and operational parameters of the engine affect its internal and external characteristics. The sensitivity can be determined when the relationship that determines the work cycle is expanded into the Taylor series, where only two first terms of the expansion are taken into account:

$$l_{ob} = l_{ob0} + \frac{\partial l_{ob}}{\partial x_1} dx_1 + \frac{\partial l_{ob}}{\partial x_2} dx_2 + ... + \frac{\partial l_{ob}}{\partial x_n} dx_n ,$$

Where

l_{ob} - effective work for a cycle of an equivalent single-flow engine

$x_1 \ldots x_n$ - selected status parameters;
index '0' refers to the expansion point.

Next, it is necessary to find out appropriate relationships between the partial differentials and selected status parameters.

Any increase of the engine compression results in continuous drop of the work cycle sensitivity to variation of the given parameter (Fig. 5 – the sensitivity of the work value within the operation cycle is related to the work value for the specific channel at the point of expansion). However, the effect is very weak, so that parameter is not used as a control factor. According to the work cycle sensitivity of the internal channel decreases in pace with increase in efficiency of the compression process (Fig. 6) but again, the sensitivity within the range of compression values that are commonly applied (i.e. η_{prs}>0.80) is insignificant, which confirms only slight effect of that parameter on the work value within the operation cycle. For more precise evaluation, how parameters of the engine thermal cycle affect efficiency of its operation, the information should be sought by estimating values of natural derivatives for specific parameters.

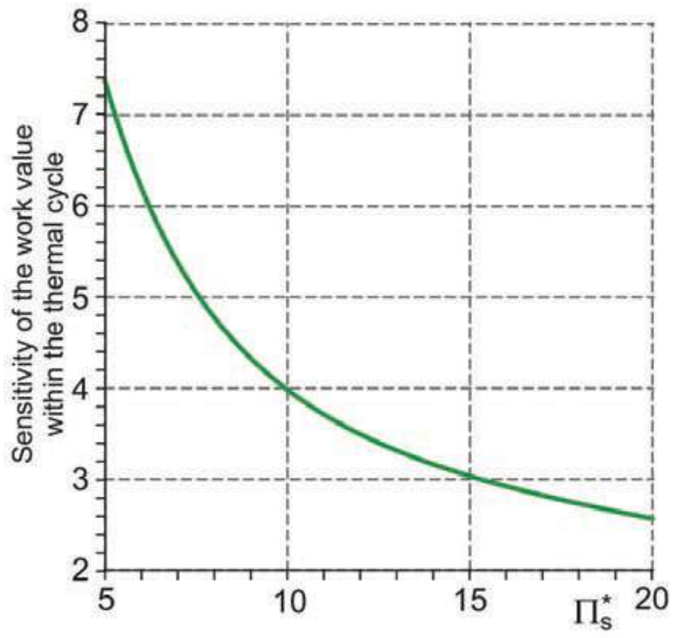

Fig.5. Sensitivity of the work value within the thermal cycle to variations of the engine compression.

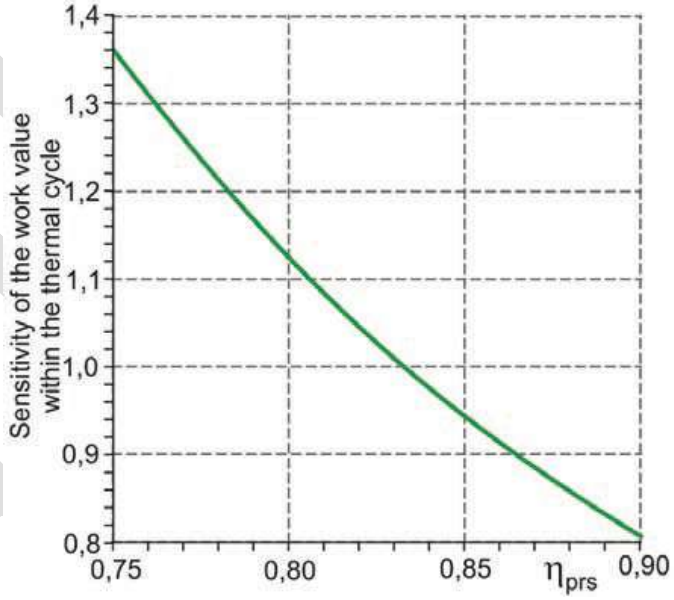

Fig.6. Sensitivity of the work value within the thermal cycle to variations of the compression process efficiency

The foregoing relationship demonstrates that increase of the split factor (degree of double-flow operation) m between two streams always leads to drop of the work value for the thermal; cycle in the external channel (Fig. 7).

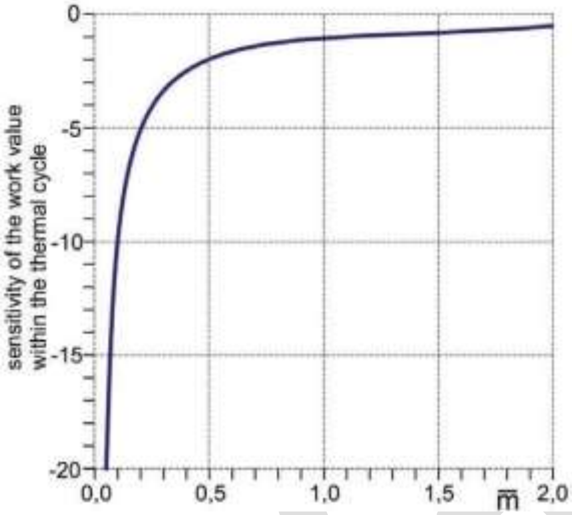

Fig. 7.Sensitivity of the work value within the thermal cycle to variation of the double flow factor used

However, the nature of the curve reveals very high sensitivity of the work value within the thermal cycle to variations of that parameter within low range of the parameter values, whereas as early as from m >1.5 the dependence is really insignificant. All the above serves as a proof that further increase of the m value above the mentioned threshold, no longer decides about the work values within the thermal cycle of the external channel. It may be the reason for the fact that for all the already examined adaptive engines the air bleeds via the external channels not more than 15 – 20%, i.e. within the limits of the highest sensitivity of the work value within the thermal cycle to that parameter.

Therefore it is impossible to unambiguously determine, how the mentioned parameter affects the value of work within the thermal cycle as the interrelationship changes in pace with variation of ϕ_M.

In case of 'bypass' motors, the sensitivity analysis for the value of work within the thermal cycle can be carry out with consideration to only the second term of the relationship as it is the term that decides about the difference in the value of work within the thermal cycle as compared to the second motor where such air bleeds are not applied. When to express the second part of the relationship in the form of functions, the following form is achieved:

$$l_{obi_2} = f\left(\nu, \Delta^*, \Pi_s^*, \bar{l}_s, \eta_s^*, \eta_m\right)$$

CONCLUSION

In summary, operation of turbojet adaptive engines is the topic that needs much further investigations. Even the design solution of the engine itself, although being really exciting and promising, is troublesome in the aspects of design, technology and shall led to a series of operation and maintenance problems. The most difficult issue seems to be a solution meant to control bleeding of air depending on the flight speed of an aircraft. Therefore future prospects for design solutions of adaptive engines are open and offer big opportunities for further development.

In addition, the degree of separation of the stream in the adaptive engines can be a parameter that adjusts the value of the working cycle engine because of its high sensitivity, especially to small values, and since m > 1.5 is very small. It may be the reason for the fact that for all the already examined adaptive engines the air bleeds via the external channels not more than15 - 20%, i.e. within the limits of the highest sensitivity of the work value within the thermal cycle to that parameter.
So, I am interested for this topic, because this is related to turbo machinery and do want to something new.

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