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POSSIBILITIES OF USING THE TYPE BYPASS AIR BLEED IN A SINGLE-FLOW JET ENGINE

Możliwości zastosowania upustu powietrza typu Bypass w jednoprzepływowym silniku odrzutowym

Abstract: *The paper outlines the analysis dedicated to possibilities of using the type Bypass air bleed in a single-flow jet engine. Attention is focused on development of formulas for key operational parameters of the engine, such as overall work of the thermal cycle, unit thrust and unit consumption of fuel. Simulation and modelling a single-flow jet engine were carried out for the K-15 engine of a Polish make where an air bleeding of that kind is applied. It was confirmed that such engines offer some slight benefits, in particular in terms of cost-efficiency, and such benefits increase in pace with growth of the mass air flow intensity through the bypass channel.*

Keywords: adaptation engine, keywords, Bypass air bleed

Streszczenie: *W artykule przedstawiono analizę dotycząca możliwości zastosowania upustu powietrza typu Bypass w jednoprzepływowym turbinowym silniku odrzutowym. Uwagę skupiono na podstawowych parametrach pracy silnika, przedstawiając obieg termodynamiczny oraz ciąg jednostkowy i jednostkowe zużycie paliwa. Symulację i modelowanie jednoprzepływowego silnika odrzutowego przeprowadzono w oparciu o silnik typu K-15 produkcji polskiej. Potwierdzono, że zastosowanie tego rodzaju upustu powietrza daje pewne korzyści, w szczególności pod względem ekonomicznym, które rosną wraz ze wzrostem masowego natężenia przepływu powietrza przez kanał obejściowy.*

Słowa kluczowe: silniki adaptacyjne, parametry pracy silnika lotniczego, upust powietrza typu Bypass

1. Introduction

One of the most appealing directions in development of turbojet engines is represented by the so called adaptation engines (where the term "engines with the variable thermal cycle" is also used in relevant literature references). That class of engines comprises a single-rotor turbojet engine of the bypass type where a portion of compressed air is conveyed via a dedicated bypass channel from downstream the engine compressor to the area downstream the turbine for the maximum range of the engine operation (such engines are designed by both Boeing and Pratt & Whitney - fig. 1).

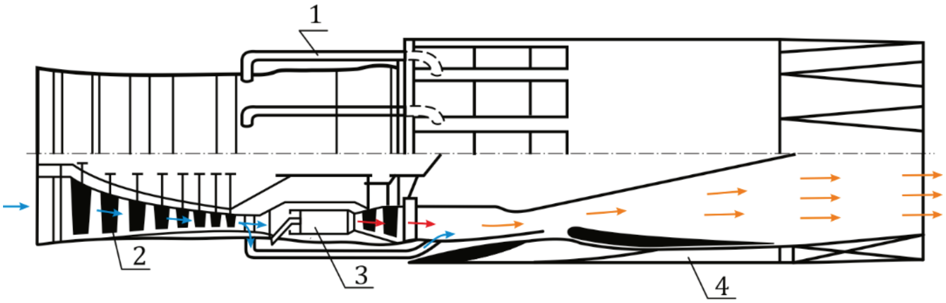

Fig. 1. Diagram of the bypass-type turbojet engine: 1 – bypass channel for air conveyed from downstream the compressor to the area downstream the turbine; 2 – adjustable compressor, 3 – combustion chamber with low level of toxic components emission in exhaust gas; 4 – discharge jest with the thrust reverser [8]

For such an engine at the maximum range of its operation (full thrust) about 25% of the air stream that leaves the compressor is bled to the bypass channel. The more the flow is throttled, the less percentage rate of air is bled from downstream of the compressor in order to maintain the constant flow intensity of exhaust gas passing through the turbine. It allows keeping the engine rpm at the desired level of 100% within the sufficient range of variations for the total and unit thrust.

The peculiarity of such a solution consists in the existence of external bypass channels with round cross-sections and a control system to adjust air bleeding depending on the aircraft speed of flight. It enables improvement of the engine efficiency, lowering the noise level and emission of toxic components in exhaust gas. Another advantage of that solution is its relatively low complexity as compared to standard solutions, which suggests the opportunity to apply it to engines that are currently in use.

2. Energy balance

The real thermal cycle for the bypass engine is a typical cycle of a jet engine, where the working cycle area varies as a function of air amount that is bled from downstream the compressor and delivered to the area downstream the turbine.

Overall work for the thermal cycle of that engine can be calculated in the following form:

$$l_{obi} = l_{ob} - \nu \varphi_D^2 c_p^{'} T_H^{*} \left\{ \Delta^{*} - \frac{B\left[\left(1+\overline{l}_s\right)c_p - c_p^{'}\eta_m \overline{l}_s\right]}{c_p^{'}\eta_s^{*}\eta_m} - 1 \right\} \qquad (1)$$

where:

$\nu = \frac{\dot{m}_{up}}{\dot{m}}$ - relative amount of air (air rate) that is bled from downstream of the compressor ($\dot{m}_{up}$ - portion of air that is bled from downstream of the compressor to the area downstream the turbine);

φ_D - factor of velocity loss in the discharge jet;

c_p, c_p' - specific heat of air and exhaust gas, respectively;

T_H^* - overall temperature of air on the intake cross-section of the compressor;

η_m, η_s^* - mechanical efficiency of the engine and the compressor, respectively;

Δ^* - degree of equivalent heating for a jet engine;

$\overline{l}_s = \frac{L_s'}{L_s}$ - breakdown of work for a compressor with air bleeding (bypass) (L_s' - the portion of the compressor work that is necessary to compress the air to be bled, L_s - total work of the compressor);

$B = \pi_S^{*\frac{k-1}{k}} - 1$ - the constant component that depends on the compression factor π_S^* of the compressor (*k* – exponent of the isentropic curve, for air *k=1.4*).

Application of the relationships for the energy balance of the flow and the thermal balance for the combustion chamber leads to formulation of other relationships, including the one for the unit thrust and for unit consumption of fuel, where the graphic curves for these relative parameters are exhibited in fig. 2.

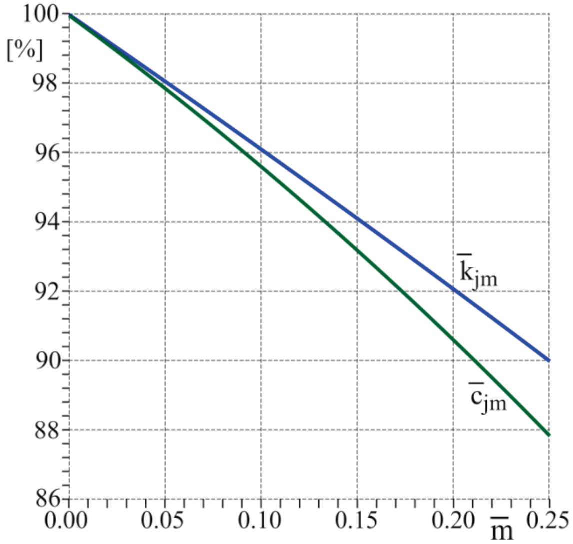

Fig. 2. Relative drop of the unit thrust and the unit consumption of fuel for bypass engines

It was found out that both parameters are subject to gradual drop but the decrease rate is higher for the unit consumption of fuel, which confirms economical properties of the bypass engines. As a consequence, higher efficiency factors are achieved for engines with higher bypass ratios, which is shown in fig. 3.

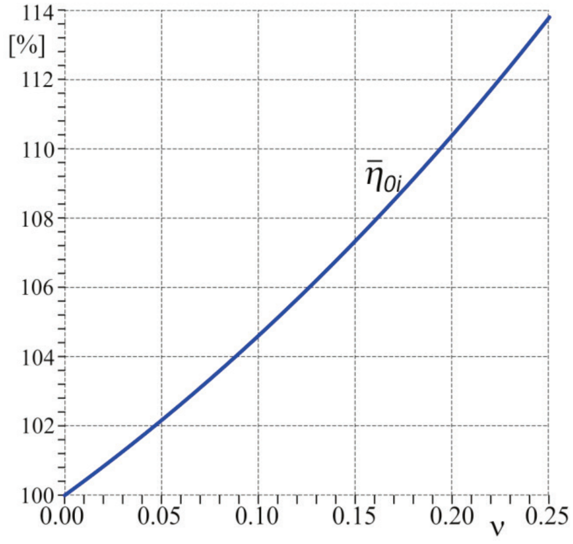

Fig. 3. Curve for the overall relative efficiency of a bypass engine

3. Possibilities of using the type Bypass air bleed in a jet engine K-15

Design solutions for the air bleeding channel suitable to bypass engines suggest that any of the relevant engineering means can be applied to upgrade the K-15 turbojet engine. However, simulating computations have demonstrated that the conditions for collaboration between the engine compressor and the turbine impose some constrains, both to the amount of bypassed air and the starting point when the bypass channel is activated. A typical graphic curve for acceleration of the K-15 engine, plotted with the use of the dedicated simulation model, is shown in fig. 4.

In turn, fig. 5 explains how application of the air bypass of that kind has led to changes in the acceleration curve for that engine.

The results revealed in this paper were achieved for 10% of the amount of air being bled to the bypass channel for the maximum and steady range of the engine operation (i.e. 94.5% of n_{max}). It was found out that the air bleeding leads to lowering of the line for collaboration between the turbine and the compressor with simultaneous increase of the margin for steady operation of the engine. It results from the fact that less power of the turbine is transmitted to the compressor, which, in consequence, reduces the compression factor achievable for the compressor.

Thus, the maximum amount of air to be bled in that way is subject to certain limitations and, in the case of the K-15 engine, it reaches 10÷15% of the total flux of air that is discharged from the compressor. When the ratio of air being bled to the bypass channel keeps growing and reaches more than 20%, the collaboration conditions are no longer maintained, which is shown in fig. 6.

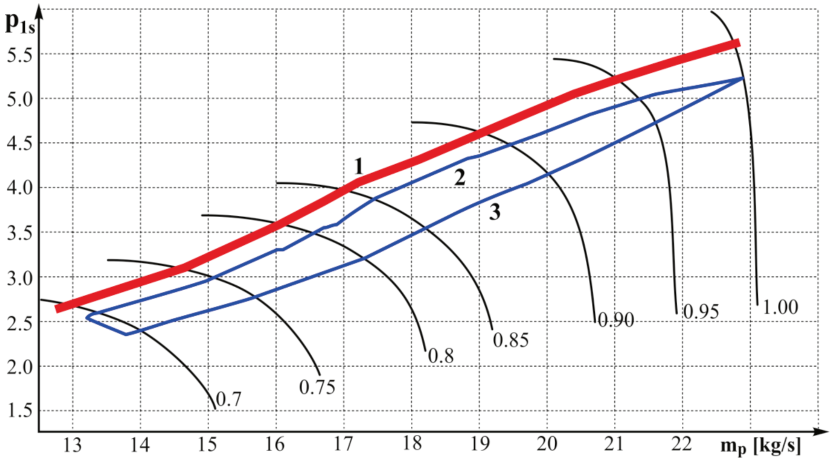

Fig. 4. Graphic interpretation for acceleration of the K-15 engine (without air bleeding); 1 – threshold for steady operation, 2 – acceleration, 3 – line of collaboration in the steady state

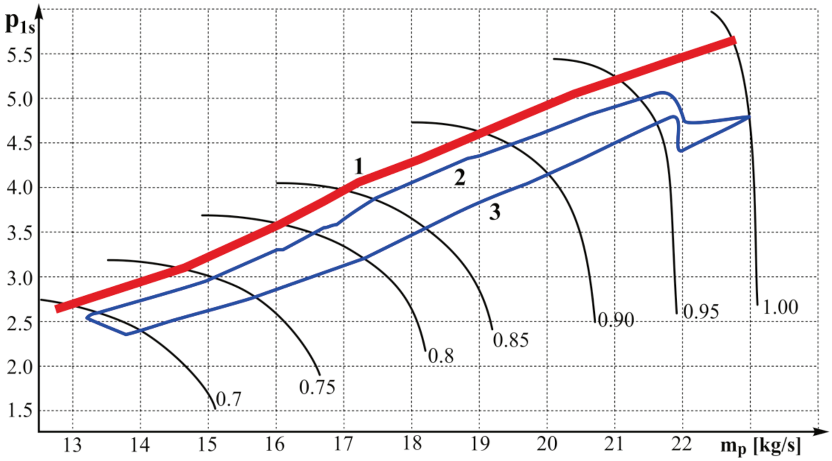

Fig. 5. Graphic interpretation for acceleration of the K-15 engine where 10% of air is bled into the bypass channel at the maximum steady operation range (i.e. ca. 94.5% n_{max})

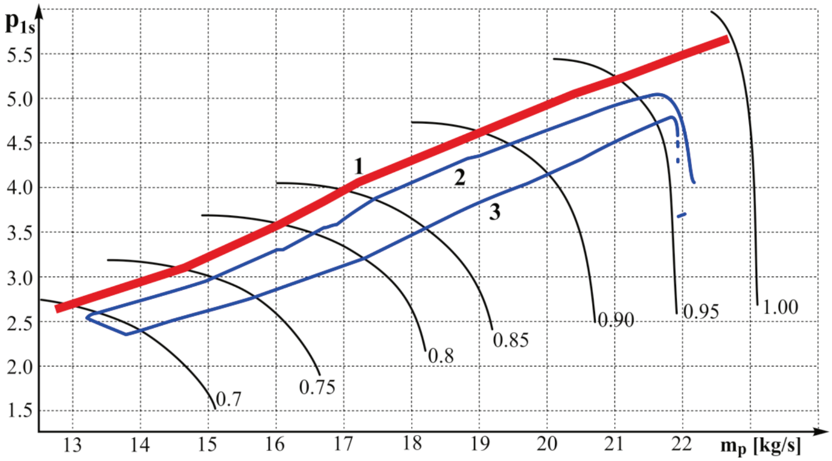

Fig. 6. Graphic interpretation for acceleration of the K-15 engine where 20% of air is bled into the bypass channel at the maximum steady operation range (i.e. ca. 94.5% n_{max})

Similar effects can be achieved when the same and already recommended amount of air bleeding is preserved with simultaneous decrease of the engine operation range (engine rpm) for which the bypass channel is being opened. Fig. 7 corresponds to the situation in which the collaborating conditions are disrupted when 10% of the total amount of air discharged from the compressor is being bled to the bypass channel but the bleeding valve is being opened at the rpm range below 90% of n_{max}.

The foregoing phenomenon is caused by the fact that the output power of the turbine decreases and becomes insufficient to drive the engine compressor, its auxiliary power packs and to overcome mechanical resistance, which finally leads to disruption of the conditions for the compressor and turbine collaboration and to engine shutdown.

The parameter that makes it possible to evaluate quality of the engine acceleration is the duration time of the acceleration process. The impact of the air bleeding rate onto the relative time of the engine acceleration process achieved for the bypass engine is shown in fig. 8.

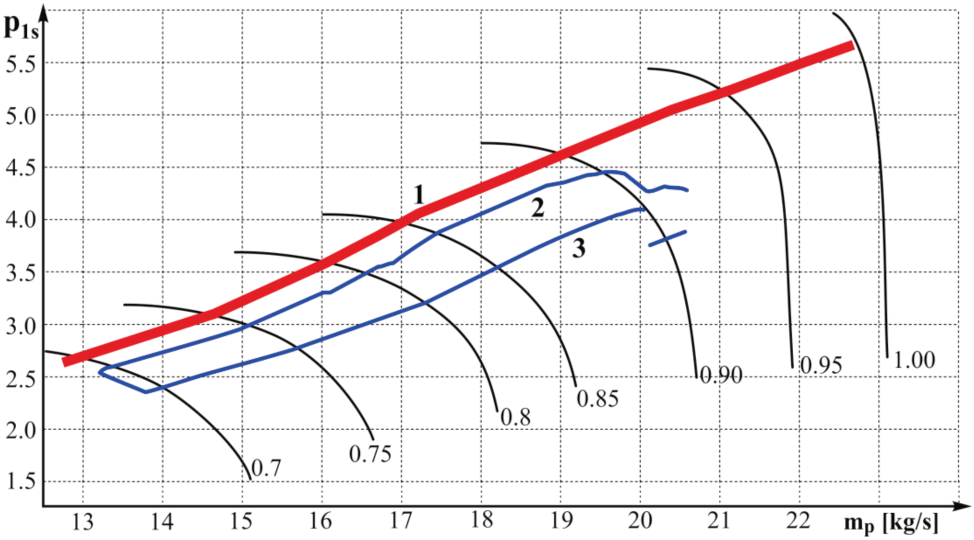

Fig. 7. Graphic interpretation for acceleration of the K-15 engine where 10% of air is bled into the bypass channel at the operation range of about 88% n_{max})

Due to intrinsic characteristic parameters specific for individual design subassemblies of the engine, the acceleration time could be measured from the minimum engine speed of about 10,500 rpm, which is ca. 66% of n_{max}. It is the real range that can be monitored when the acceleration time of the K-15 engine is measured during its regular operation (except for full-range acceleration). According to the technical documentation of the engine, that time period measured for the range from 66% to 95% of n_{max} should not exceed 4 seconds.

However, due to the need to reveal the actual impact of air bleeding to the bypass channel onto the acceleration time of the engine, the simulation computations were spread onto the range from 66% to 99.5%. It was caused by the fact that bleeding at the maximum rpm for steady operation of the engine ($n \approx 94.5\%\ n_{max}$) has nearly no impact onto the acceleration time, regardless the bypass rate. The actual impact was observed only for the range above 95% of n_{max}, which is the range that cannot be measured during regular operation of the engine. In addition, the acceleration time was measured for the amount of air being bled to the bypass channel ranging from 0 to 15% of the total air amount discharged by the compressor. Exceeding of the threshold of 15% led to disruption of the conditions of collaboration between the compressor and the turbine, which disabled measurements of the acceleration time.

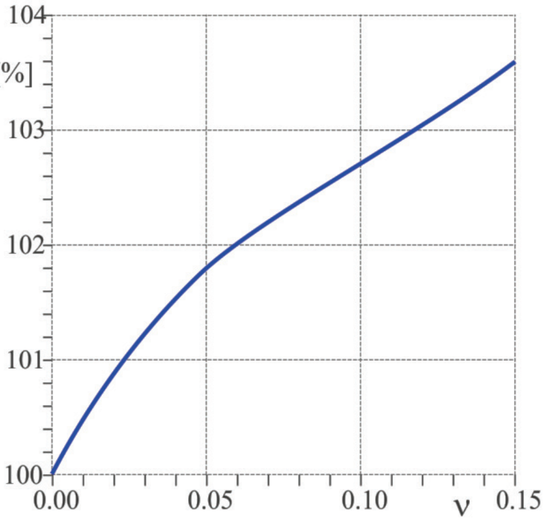

Fig. 8. Variations of the relative time of the engine acceleration as a function of a relative amount of air being bled from downstream the compressor to the area downstream the turbine

The analysis of fig. 8 makes it possible to find out that the acceleration time increases in pace with the amount of air being bled into the bypass channel. The impact is slightly more significant (up to nearly 2%) when the rate of bypassed air is less than 5%.

Finally no significant prolongation of the acceleration time was revealed due to implementation of such air bleeding method and no substantial retardation for the engine to reach its maximum operation range was detected.

4. Result and conclusion

The simulation modelling demonstrated that implementation of air bleeding facilities is possible for existing turbine jet engines. It was confirmed that air bleeding to the bypass channel can start at the engine operation ranges (engine rpm) even slightly less than the maximum rpm, which suggests the opportunity to achieve even more benefits, chiefly due to reduction of the fuel consumption per power unit. Unfortunately, it is still associated with some constrains that directly depend on the amount of air that can be bypassed via external channels from downstream the compressor to the area downstream the turbine. Such amounts can be increased in pace with the total flux of air through the main flow channel of a jet engine. It means that more significant benefits from air bleeding solutions of that kind can be achieved for large-sized jet engines. It is why application of these design approaches is deemed suitable to power supersonic passenger and cargo aircrafts. There are also attempts to use such engines to power supersonic strategic bombers or strike fighters. There also ideas to apply the operation principle of adaptation and stream jet engines to power hypersonic aircrafts capable of reaching the flight velocity Ma>4.

5. References

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