THE JET-PROPELLED AERO-ENGINE EXHAUST ARRANGEMENT

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The article tries to approach the issue of system output, first in terms of distribution and description of the output system, then in terms of temperature control gas output in these systems and also describes a specific set of output engine RD-33rd. Finally a static model developed in the MATLAB environment presents the program of section change nozzles depending on the position of TL. Materials to final processing have been collected from various sources from leading DT, the TU library, teachers at FA and websites.

K e y w o r d s: engine, propelling nozzle, nozzle - throat area, afterburner, maximal , thorttle lever (TL)

1 INTRODUCTION

Aircraft engines serve to power aircraft and consists of several functional components, depending on the type of engine, each type features an output or exhaust system. The current aircraft engines use different types of output systems, which the design mainly affected by the use of the aircraft, its flight regimes and location in an aircraft engine.

2 OUTPUT SYSTEM OF AIRCRAFT ENGINES

The main task of the output system of engine is to convert pressure and partly thermal energy into kinetic exhaust gas as efficiently as possible. Another very important tasks of the output system are the off-take of gases from the combustion process of engine, guiding it current (engine exhaust gases) in axial direction and regulating turbine operation and thus the entire engine. and control work turbine and thus the engine.

Apart from the main function to shape the outlet pulse, the exhaust system ca serve other functions depending on the engine designation:

.aircraft control using thrust vectoring (including thrust reversal)

.reducing the infrared and radar prints,

.reduction of noise,

.transmission of the outlet (turbo-shaft)

The equipment within which the static pressure decreases during gas flow, speed increases and while the potential energy is converted into kinetic energy of flowing is termed as jet pipe.[5]

3 DISTRIBUTION OF OUTPUT SYSTEMS

3.1 Non-adjustable output agitating mechanisms

Non-adjustable nozzles are mainly used in engines without afterburner. To achieve a very uniform velocity field at the outlet nozzle should be shape nozzle so that pressure gradient towards the discharge section decreased and at the end of the nozzle reaches zero. The shape of the outlet nozzle flow is determined by a number of changes in gas pressure at the nozzle and the requirements for operation of the motor, at which we want to achieve the maximum efficiency. At very small to the critical values of pressure, which is typical for motors transport and transport aircraft with a cruising speed of 900 km / h nozzles have a tapered shape. The geometry of the nozzle channel is constant and optimized depending on flight cycles or often by travel mode.[5]

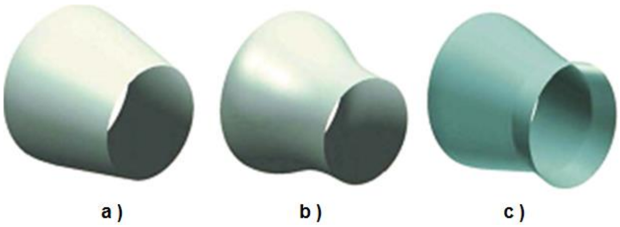

Figure no. 1 Types of non-adjustable nozzles, by [5]

Where:

a) Conical nozzle,
b) Vitoshinsky nozzle,
c) Laval nozzle.

3.2 Adjustable output mechanisms

If the degree of pressure reduction π_{smax}> 2.5, losses in fixed nozzles in some modes of operation of the engine may become unacceptable. In this case and also in the case of an engine with afterburner, there is a need to change the area of the criticalcross-section and when π_{smax} >> 2.5 and that of the exit section, as well as the shape of the nozzle channel in the process of changing the engine work to change the flight.

Nozzles operating on this principle are called controllable nozzles.[5]

This includes:

- axially symmetric adjustable nozzle

Figure no. 2 Adjustable nozzle with segments, by [5]

- flat nozzle

Figure no. 3 Flat nozzle, by [7]

- axially symmetric nozzle with adjustable swivel hub

Figure no. 4 Axially symmetric nozzle with adjustable swivel hub, by [5]

- outlet nozzles of aircraft engines and aircraft accelerated vertical takeoff and landing

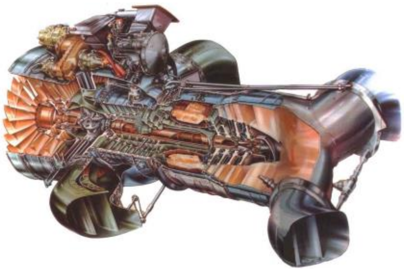

Figure no. 5 Engine Rolls-Royce Pegasus with 4 nozzles, by 0

- invisible output system.

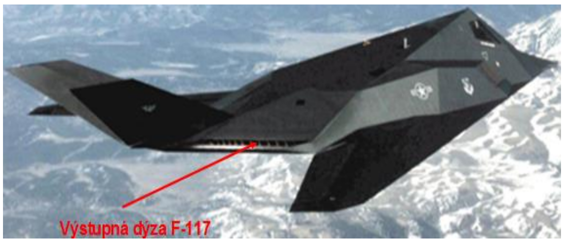

Figure no. 6 F-117, by [9]

4 AUTOMATIC SYSTEMS OF REGULATION GASES TEMPERATURE

Systems of gases temperature regulation are designed so that at constant TL they maintain the set value or change it depending on flight conditions and the position of the TL.

Distribution of gases temperature regulation systems:

- open – program-based, with compensation for disturbances,
- closed, operating on the principle of measuring variatnces from the desired value,
- combined

4.1 Closed systems of gases temperature regulation

a) With electronic correction periphery

Automatic systems of regulation temperature T_{4C} are composed of two parts:

- electrical - initial management signal processing,
- hydraulic - changing electrical signal to change the nozzle exit cross-section A_{5KR}.

Amplified and corrected signal is fed to an electromagnetic transducer, which is part of the power electronic block regulator T_{4C}. One of the input amplifiers performs apart from amplification signal the function of of comparing the thermocouple periphery.

The signal proportional to the desired value T_{4CZ} is formed in the program-based adjusting unit (PAJ) as a function of αTL and other control signals.

When increasing T_{4C} compared to T_{4CZ} , substitution of pulses increases and will ensure opening outlet nozzle through an actuating member and hydraulics.

By opening of the outlet nozzle the pressure drop across the turbine increases and turbine torque increases. Consequently, rpm increases, at which the speed controller is reacting by reducing the supply of fuel to the main combustion chamber (MCCH).

This will reduce the temperature and the T_{4C} system enters the steady state.

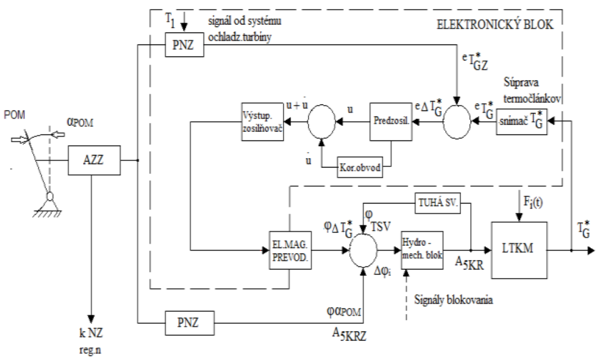

Figure no. 7 Closed systems of regulation gases temperature, by [3]

b) Closed systems of gas temperature regulation acting on the A_{5KR} connected in series with the regulator of the pressure drop at the turbine π_T.

Dynamic properties of automatic temperature control systems can be improved by using fast working controller functioning as a correction element, connected in series with the automatic systems of gas temperature regulation.

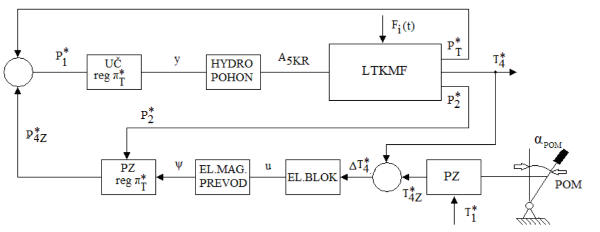

Figure no.8 Closed systems of gas temperature regulation, by [3]

Pulse signals from the output amplifier are fed to an electromagnetic transducer, in which they are converted into slider oscillation. To facilitate practical implementation of the controller π_T the real value π_T is not measured. Its value is regulated indirectly by controlling the pressure p_n, which is compared with the pressure specified p_{4z}. Pressure p_{4z} is obtained in the programming equipment - pneumatic reducer. Pressure is obtained in the programming equipment - pneumatic reducer, which is a throttle needle imitated expansion of air pressure p_2 on the pressure p_{4z} .

Then $p_{4z} = p_4/\pi$ (1), while value π_{TZ} (degree of reduction in the pneumatic reducer) is set through a powerful mechanism from the temepráture regulator – by an electromagnetic transducer. The value π_{TZ} corresponds to the required value of temperature T_{4C} .

The regulator π_T on detecting the difference $\Delta p_4 = p_{4z} - p_4$ (2) provides the signal for the hydraulic drive for change A_{5KR}, until state $p_4 = p_{4Z}$ (3) occurs. [3]

4.2 Open systems of gas temperature regulation

a) Open systems iaffectiong the critical cross-section of the outlet nozzle

Whereas closed systems, temperatures are difficult to implement practically, initially open automatic temperature regulation systems were used to influence the **cross-section of the outlet nozzle *A_{5KR}*.**

In open systems, automatic control of gas temperature, the outlet nozzle cross section may vary by various functions:

- $A_{5KR} = f(\alpha_{POM})$, (4)
- A_{5KR} is a function of one of the parameters engine, for example n, p_2, π_k, π_T.

Open systems of gas temperature regulating act on the outlet nozzle area, climate critical section nozzle are changing the pressure drop across the turbine. In conjunction with the speed governor, it is to set temperature T_{3C} or within a temperature range.

Because the system does not have feedback, it must be designed so that the temperature did not exceed T_{4C} for any conditions. Otherwise, you must use the limiter of temperature T_{4C}.

b) Positional automatic devices of outlet nozzles

Although the change in the critical section outlet nozzle always results in a change of heat load on the engine and the T_{4C} temperature change, the critical section of the nozzle change should not be changed in the first place just to achieve a change temperature. The primary objectives may be different.

They can be for example:

- improve the engine startup performance,
- improving engine acceleration capabilities,
- removal of unstable compressor work,
- removal the decline takeoff thrust under, conditions of higher air temperature,
- improve the economyof work for different modes of flight (cruising mode).

c) Management of the outlet nozzle in afterburner modes

This program of the the outlet nozzle diameter control is representing the functions among the outlet nozzle cross-section, high pressure compressor speed and α_{POM} engine R-13, which is a single-spool engine with a three-stage low-pressure, five-speed high-pressure axial compressor, taking the air bleed system for boundary layers of the flaps, a major mixed-combustion chamber, single-stage high pressure cooled gas turbine, single-stage uncooled low-pressure gas turbine output array with afterburner chamber, extension tube and an adjustable discharge nozzle, critical step to control the diameter of the modes without afterburner and stepless critical diameter of the switched modes with afterburner on.

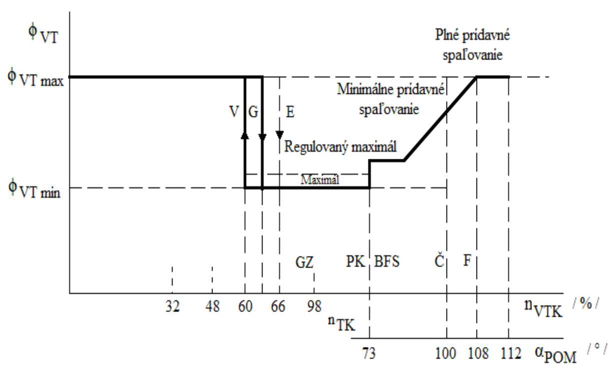

Figure no. 9 The outlet nozzle management program, by [3]

At low operating speeds (up to 60 – 66 %) the outlet nozzle is open to the maximum diameter, thereby facilitating startup, launching, while in the idle-run mode and modes close to it the engine runs at low gas temperature, low-thrust and low fuel consumption.

When the rpm n_{VTK} reach 66 %, the output nozzle narrows down to the mechanical stop of the minimum cross section. This constant diameter is set up to the maximum mode included. At α_{POM} = 73° the afterburner mode is activated and the output nozzle opens into position corresponding to the diameter of the outlet nozzle of the minimum afterburner.

Whereas the afterburner can only turned only when the low pressure compressor rotor will be 98%, and the microswitch GZ is clapped. By gradually moving in the direction of full TL, additional combustion (in α_{POM} = 108 °) results in a smooth opening of the nozzle thereby in achivieng incremental setting of the afterburner as high as up to the maximum value.[3]

5 THE RD-33 ENGINE

a) Adjustable output nozzle

Adjustable output nozzle of engine RD-33 is supersonic, with Laval type of independent variability of the critical and external diameter by regulatory programs indepentednt from each other.

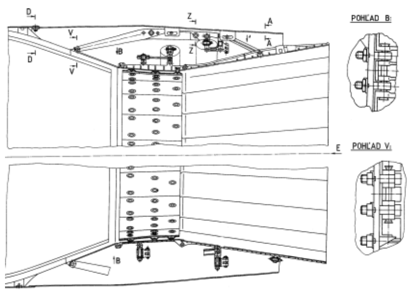

Figure no.10 Al-mode, adjustable output nozzle of the RD-33 engine , by [4]

b) Regulatory Laws of the RD-33 engine:

Regulatory parameters of the RD-33:

- fuel supply to the main combustion chamber Q_p (kgh^{-1}),
- critical cross-section supersonic nozzle exit A_{5kr} (m^2),
- output cross-section of the supersonic nozzle exitA_{5v} (m^2),
- fuel supply to the afterburner combustion chamber Q_{pKPS} (kgh^{-1}),
- angle of attack of the guide vanes of the high pressure compressor at stage 1 and that of the high pressure compressor α uú1.a at stage 2, αuú2. (°).

Regulated parameters of the RD-33:

- rpm of the high pressure compressor n_k (min^{-1}),
- rpm the fan n_d (min^{-1}),
- gas pressure in the outlet section of the supersonic outlet nozzle $p_{5v'}$ (Pa),
- gas temperature in the afterburner chamber T_{5c} (K),
- supply of stable work of the high pressure compressor Ky.

The relationship between the regulatory and the regulated parameters of the RD-33 engine as expressed by regulatory laws**:**

$$n_k = f(Q_{p,HSK}), \tag{5}$$
$$n_d = f(A_{5,kr}), \tag{6}$$
$$p_{5,v'} = f(A_{5,v}), \tag{7}$$
$$T_{5c} = f(Q_{p,KPS}), \tag{8}$$
$$Ky = f(\alpha vu\acute{u}\ ,\ \alpha u\acute{u}1\ ,\ \alpha u\acute{u}2). \tag{9}$$

6 MODELING THE ACTIVITIES OF THE TURBOUJET ENGINE OUTPUT SYSTEM OF A SELECTED AIRCRAFT

6.1 Model of the channel regulating the fan rpm n_D and starting run n_D

Program of regulating the fan rmpm n_D depending on the overall temperature entering the engine T_{1C} is divided into the following three temperature sections:

1.section : – 68 as much as 15° C,
2. section : 15 as much as 73 ° C,
3. section : 73 as much as 215 ° C.

Model of channel regulation air speed of blowers is a ***static model***, which forms the interdependence of the converted fan rpm on the total temperature at the engine inlet.
We analyze development of the model in three basic steps.

In the first step, we analyzed both the characteristics, whereby we obtained data on under which we created mathematical functions that describe the behavior of the regulation system in various sections of the regulation. The system is linear, the individual regulatory sections describe linearly increasing and decreasing functions in the form of straight lines. The main task in the first step was to determine the slope of the line and the points of crossing zero on the axis x.

In the first section of the regulation within the total temperature at the inlet T_{1c} od - 68 °C do +15 °C, the slope was calculated as the ratio of marginal gap of boundary values x and y of functions:

$$y = k\ .\ x + q \tag{10}$$

boundary values **y**:

y_{max} = 97,6 %
y_{min} = 82,4 %

Δy:

$$\Delta y = 97{,}6 - 82{,}4 = 15{,}2\ \% \qquad (11)$$

boundary values **x** :

x_{max} = 15 °C
x_{min} = - 68 °C

Δx:

$$\Delta x = x_{max} - x_{min} = 15 - (-68) = 15 + 68 = 83\ °C \qquad (12)$$

slope **k** :

$$\frac{\Delta y}{\Delta x} = \frac{15{,}2}{83} = 0{,}18313 \qquad (13)$$

Next, we determined the first section of zero crossing point in the graph i.e. the q = 95%. From the calculated values, we have obtained the resulting equation describing the regulation in the first section :

$$y_1 = 0{,}18313 \,.\, x + 95 \qquad (14)$$

At the remaining two sections of the regulation we proceeded in the same way:

$$y_2 = 0{,}05862 \,.\, x + 96{,}42 \qquad (15)$$
$$y_3 = -\,0{,}045774 \,.\, x + 103{,}1 \qquad (16)$$

Creating the model itself in the Matlab - Simulink program was part of ***the second step***. Introducing the calculated constants into the model in Matlab resulted in some inaccuracies, so we decided to tune the model, representing ***the third step***.

We tried to find such values for constants k and p, including the supplementary variable, so as to achieve maximum similarity between the established system and the developed model.

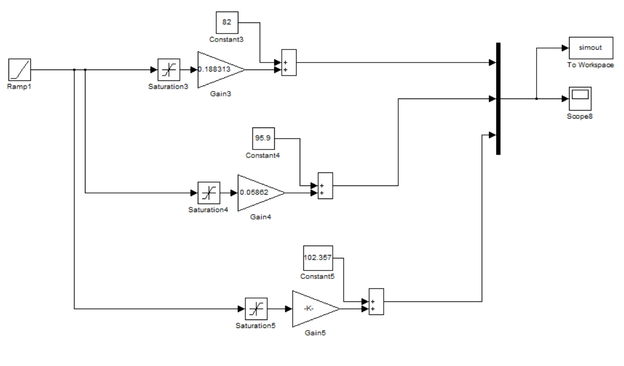

Figure no.11 Model of the fan rpm regulation cahnnel

The model developed is fairly corresponding to the required one, except that it is shifted along the axis x by 68 ° C to the right, and begins at 0.The given shift did not change neither the function notr the meaning of the regulation channel.

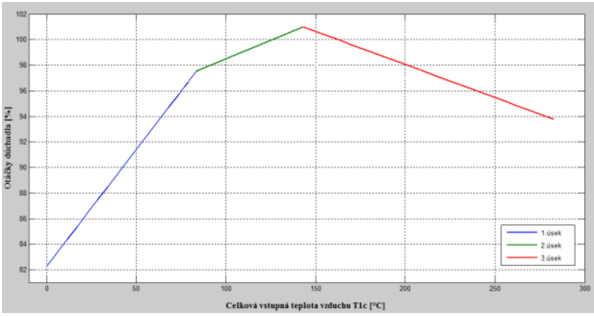

Figure no. 12 Model of the channel regulating the rpm the fans in the Matlab – Simulink environment

6.2 The model of the program changing the critical cross-section outlet nozzle depending on the engine throttle lever

The program of changing the critical section outlet nozzle is adjusted depending on the mode, because α_{POM} determines the supply of fuel to the main combustion chamber, being understood $Q_{p.HSK} = f(\alpha_{POM})$ (17) with correction on the temperature T_{1c}. Between the lever engine control and pump motor there is a direct mechanical linkage. Moving the engine control lever the given mode is set.

Depending on the mode, there is a change of the critical cross section of the outlet nozzle.

The course of the change of the critical cross-section of the outlet nozzle is adjusted so that in each mode the optimum expansion takes place in the gas outlet nozzle, i.e. in the critical cross-section.

During the engine start-up the output nozzle is fully open to ensure maximum pressure drop across the turbine and thus its maximum torque.

As a result, the temperature is lower T_{4C}, rpm in idle run mode are higher all that at an acceptable minimum thrust. When increasing rpm, the outlet nozzle is turnin blind to help the engine operate at higher temperatures T_{4C} thereby achieving higher thrust.

At maximum mode (MAXIMAL) the critical cross-section of the outlet nozzle is set to the minimum or is closed in steps to achieve maximum thrust and temperature. At maximum engine rpm a maximum temperature T_{4C} and maximum thrust is achieved. To activation of the afterburner, and inhibit further increase the temperature before the turbine, the cross-section of the outlet nozzle is opened to eventually activate the afterburner.

The described model is a static model, which is a precondition for the creation of a dynamic model and also to the further development of this model in a final thesis on similar topic.

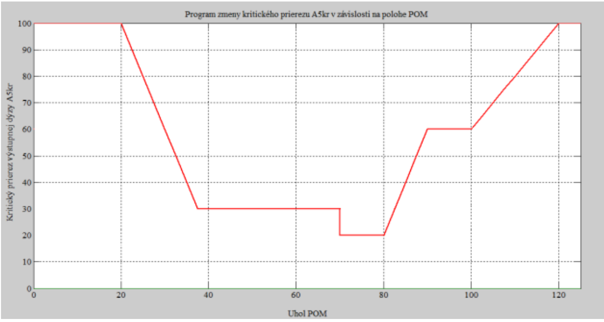

Figure no. 13 The model of the change program depending on the position of the throttle lever, developed in the Matlab – Simulink environment

7. CONCLUSION

The present article is devoted to the issue of the output systems of jet aircraft engines. The introduction is devoted to the general concepts of the term system output of aircraft engines. Then it continues with the division outlet systems in terms of function and design of output nozzles. Part three of the article is presenting automatic control systems of exhaust gases, distributed and individually dealt with theoretically, graphically and mathematically. Part four describes the RD -33 aircraft engine both from design point of view and in terms of automatic control, also describing regulatory laws and the problem of the limit regulators block. A separate part is devoted to two static models describing the two different operations taking place in the RD-33 and R-13 engines

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BIBLIOGRAPHY

[1] Theory of aircraft engines, part II., Prof, Ing. Jezef Růžek, DrSc., Doc. Ing. Petr Kmoch, CSc., U-1275/II, 1983, s. 68 - 110.
[2] Engine RD-33, Short Description for ČVO-431, Ing. Marián Hocko, PhD.,1994, Košice s. 4 -32
[3] Automatic electrical systems for aircraft engines turbo supercharged, Č.j :1722,pplk.Ing.František Martinec, Košice, 1992 s. 141-167
[4] Manual of the engine RD-33, Ing. Marián Hocko,PhD., Košice, Translation
[5] Газотурбинные двигатели, А.А.Иноземцев, В.Л.Сандрацкий, ОАО «Авиадвигатель», 2006 г., s. 535 – 599
[6] Associated Aerospace Activities, Inc., ISO 9002 Certified [online].[cit.2013-04-06]. Available online at: <http://www.aaai.com/news/Hardware.htm >
[7] F-22 thrust vectoring nozzles, [online].[cit.2013-03-21]. Available online at: < http://www.youtube.com/watch?v=cTCGJAoAz_8 >
[8] Yak-38 Lift Engines [online]. [cit. 2013-04-12]. Available online at <http://en.wikipedia.org/wiki/File:Yak38 Lift_Engines_NT.PNG >
Aircraft engines, [online].[cit.2013-04-15]. Available online at <http://www.leteckemotory.cz/motory/rd-33/ >
[9] AircGlobal Security, [online].[cit.2013-04-05]. Available online <http://www.globalsecurity.org/military/systems/aircraft/f-117-pics.htm >

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