OPTIMAL ENGINE CONTROL WITH TWO DEGREES OF FREEDOM

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In this paper devoted to the optimal engine control with two degrees of freedom will be processed about jet engine control, where will be described effects of controlled parameters to the regulated parameters. The main contribution of this paper is part, which deals with design of engine control MPM-20 for maximum thrust in every time. There will be described the way of nozzle changing, which is located in laboratory. In conclusion there will be theoretically calculated thrust that we acquired at this optimal control of MPM-20 engine.

K e y w o r d s: optimal control, small jet engine MPM-20, nozzle regulation, engine with two degrees of freedom

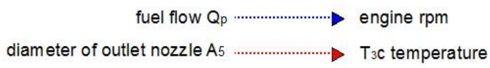
1 INTRODUCTION

MPM-20 engine, which is located in the laboratory of intelligent control systems of aircraft engines passed during many years of its research with several modifications. The current state of the engine at the time of writing this work is that the MPM-20 engine is controlled by only one parameter, which is fuel flow. Therefore, MPM-20 engine is characterized as an engine system with one degree of freedom. At this time, there is proposed mechanism that will control outlet nozzle, therefore, MPM-20 will be rebuilt to the engine with two degrees of freedom in the near future. Using this nozzle there are opening new possibilities of controlling the engine by changing a second parameter which is diameter of nozzle. By certain engine control programs, we can control engine with two degrees of freedom more effectively. Applying a controllable outlet nozzle gives us the possibility of economic engine management with minimum fuel consumption or engine control to the maximum thrust. The purpose of this paper is to design an optimal management of MPM-20 engine with two degrees of freedom, by creating a program that will change the diameter of the outlet nozzle, so we can achieve the desired result, for example get maximal possible thrust at any time.

2 CONTROLLING OF TURBINE JET ENGINE

The turbine engine works on principle, that compressor sucks air through the inlet system and compresses it. Compressed air flows into the combustion chamber where the fuel is injected into it. As a result of fuel combustion under constant pressure, the temperature of the gas is getting higher and also its thermal energy. Air flows to turbine blades, where it gives some energy to turbine, which is used to drive the compressor. Air behind the gas turbine has still higher pressure than the surrounding atmosphere and so the pressure changes into kinetic energy, which generates thrust. [2]

A single stream engine with fixed geometry has only one variable parameter which is fuel flow Q_p. The engine is thus controlled by changing the fuel flow which affects engine rpm. This engine is in terms of management less accurate, but the construction is simpler. With the engine with one degree of freedom is difficult to implement management by a program, for example management with minimum consumption or maximum thrust. Engine with variable geometry has several degrees of freedom and thermodynamic process is not only determined by fuel flow, but also by changing the geometric variables, acting in the role of additional regulation variables. Change of engine diameters is most commonly achieved using a controllable outlet nozzle. Changing a nozzle section affects gas temperature T_{3c} before the turbine and by optimal management we can control engine more effectively.[3]



3 PROPOSE OF ENGINE MPM-20 WITH TWO DEGREES OF FREEDOM CONTROL TO MAXIMUM THRUST

System with adjustable nozzle is used to change the pressure gradient on the gas turbine, and thus the change engine rpm, temperature before the gas turbine and outgoing gas velocity and thrust. From aircraft engine theory results that to each stable operation of engine with variable nozzle, will fit a certain amount of fuel flow Q_p and a certain nozzle position A_5. To select the mode of operation of the engine between idle and maximum mode, there have to be control mechanism. Control engine program with variable outlet nozzle can be chosen from the certain point of view as optimal. I focused on optimal engine control so that the engine will be controlled on every time, that means that at each position of control lever engine will get maximum thrust. [4]

In program control for maximum thrust is necessary to maintain a constant rotor rpm on maximum value n_{max} and constant value of maximum temperature T_{3c} before the turbine. This program ensures maximum thrust in working conditions. Both regulated parameters must be assigned to the control parameters. In this arrangement of the input and output variables, we obtain a system with two inputs and two outputs (TITO). Figure 1 shows that maximum rpm control will be realized by changing the parameter Q_p and control of maximum temperature will be realized by the parameter A_5. [4]

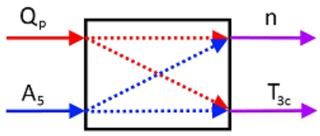


Fig. 1 Cross-links in engine with adjustable nozzle

For the safe operation of the engine is necessary to restrict some parameters in order to avoid physical damage to the engine.

4. SYSTEM WITH TWO DEGREES OF FREEDOM

Task which I am solving in this paper is to propose the optimal management of system with two degrees of freedom which is already created. In this system there is described the impact of controling variables to regulated variables, but we need to change values of fuel flow and nozzle diameter separately to see their impact on engine rpm and temperature T_3c. There is no direct connection from fuel flow to outlet nozzle. My goal is to automaticaly regulate the diameter of the outlet nozzle the way that gain us the maximum thrust.

In the past, there were many measurements on engine MPM-20 to identify the system. From measured data there were created transfer functions by different methods. In my work I will use transfer functions acquired by Stefan Bašista in [5] and Jozef Breza in his final work [6] in previous years.

To be able to create a system where the diameter of the outlet nozzle will be automatically regulated we will need basic technical data of nozzle. Output nozzle is controlled by servo motor, which rotates helices. Rotating of helice moves arm that is connected directly to nozzle segments, which changes nozzle diameter. Diameter of the outlet nozzle can change smoothly from the largest value, which is 15.2 cm to a minimum of 10.5 cm. It means, that the maximum change of nozzle is 4.7 cm. To change the position of the nozzle from the minimum to the maximum diameter we need 24 rotations of helice. From a structural point of view and the number and placement of sensors we can sense every ¼ turn of helice. While changing the diameter from the maximum to the minimum we are able to sence 96 positions of helice. In every quarter of turn of helice we will change the nozzle diameter approximately about 0.05 cm. Another important figure is the rate of change of the nozzle. In the laboratory there was measured value 4.2 s, which is the time it takes to fully open the closed nozzle.

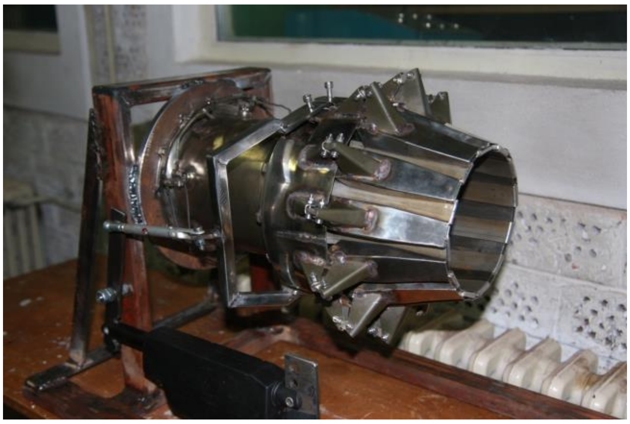


Fig. 2 MPM-20 nozzle on testing stand

5. SYSTEM WITH AUTOMATIC SETTING OF DIAMETER OF OUTLET NOZZLE IN MAXIMUM THRUST MODE

Engine control has been designed using the Matlab and Simulink program. At this time we will describe the basic blocks, which are shown in fig.3. Block initial adjustment nozzle is used to set the starting position of the nozzle. The value in this block is 15.2, which represents the maximum nozzle diameter. The Saturation block sets range of diameter of the outlet nozzle in cetimeters. The upper limit is set to 15.2 and 10.5 cm to the bottom limit. Higher or lower values will be ignored and the system sets the highest respectively the lowest value. Output "change of nozzle diameter", will characterize the current position of the nozzle at the time. The most important block that outputs the data necessary for the management of the nozzle is block fcn. It contains an algorithm that reads the temperature T_{3c} and creates value, that will determine new nozzle position. This value is subtracted or added to a initial value of the outlet nozzle. Fcn block algorithm is following:

```
function y  = fcn(u,v,t)

        if (mod(v,0.04) == 0)
              if (u < 1000)
              y = t+0.05;
              else
              y=t-0.05;
              end
         else
              y = t;
         end

end
```

The algorithm that I designed and created is based on the original TITO scheme. The entire system operates on this principle. The fcn block reads temperature T_{3c} every 0.04 seconds and compares it with the specified temperature 1000°C. Temperature T_{3c} may not rise above 1000°C. Then there is given order to open or close the nozzle of 0.05 cm. This cycle repeats and always maintain the temperature at the maximum 1000°C, which satisfies the condition T_3c_{max} that give us maximum thrust. Dynamics of changes, which fcn block operates the outlet nozzle diameter corresponds to the real management of the outlet nozzle with actuator.

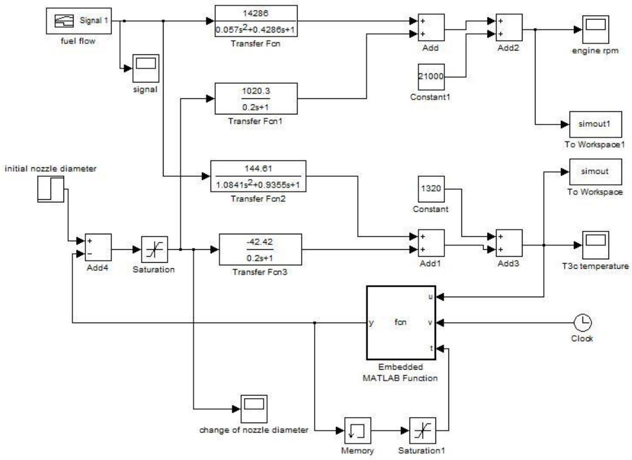


Fig. 3 Block scheme of the system with two degrees of freedom with regulated nozzle

Simulation 1

In this simulation, we will be able to see on graphs how the whole system works. Entry value will be the fuel flow, which will be rising continuously from 0.99 to 1.28 l / min and nozzle set to maximum diameter. The aim of the system will be such regulation, when algorithm will be adjusting the nozzle to maintain maximum T_3c teperature which will provide maximum thrust in any time. The simulation lasted for 15 seconds and we can see change of the fuel flow, engine rpm, temperature T_3c and change of nozzle diameter on the graphs.

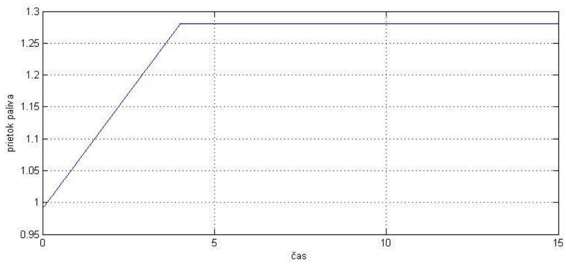


Fig. 4 Change of fuel flow at time

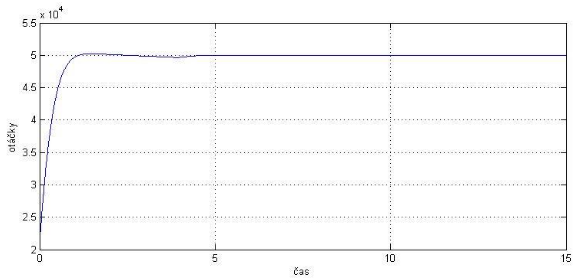


Fig. 5 Change of engine rpm at time

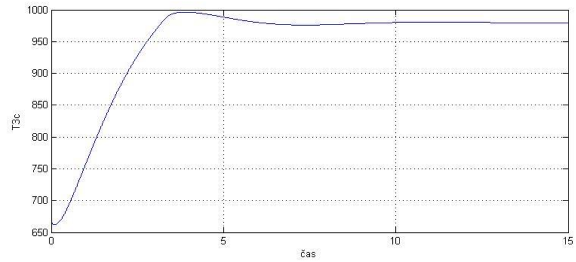


Fig. 6 Change of temperature T_3c at time

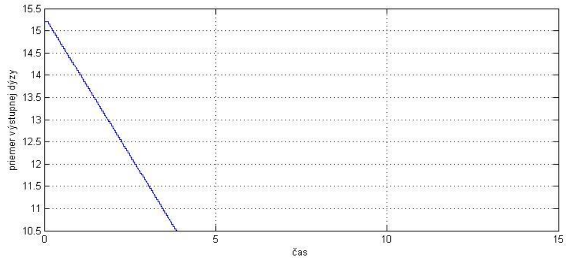


Fig. 7 Change of outlet nozzle diameter at time

We can see changes in time of fuel flow from zero to the maximum value on fig.4. Engine rpm reaches a maximum value before maximum fuel flow is achieved, which is caused by reducing the diameter of the outlet nozzle. Engine rpm decrease from approximately 1. to 4. second is caused by nozzle closing. In this case the progress of T_3c temperature is important to watch especially in stable mode. The maximum temperature T_3c is reached when the diameter of nozzle is minimum and then decrease slightly. In this simulation were such conditions that the temperature did not reached a maximum value of 1000 ° C. The nozzle was thus closing to the a minimum value.

Simulation 2

In this simulation were set such initial conditions, that if the outlet nozzle did not start to open, the temperature would exceed the maximum value. Fuel flow rised to a maximum value, then it leveled and descended again. From 10th second we can see how the nozzle will behave with decreasing fuel flow. The simulation results are shown in these graphs.

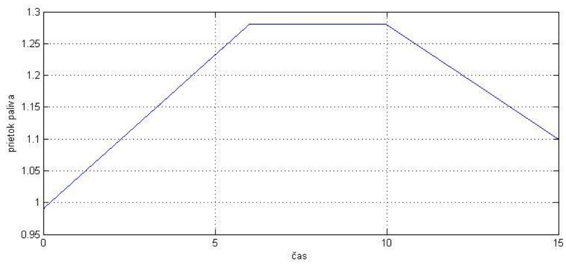


Fig. 8 Change of fuel flow at time

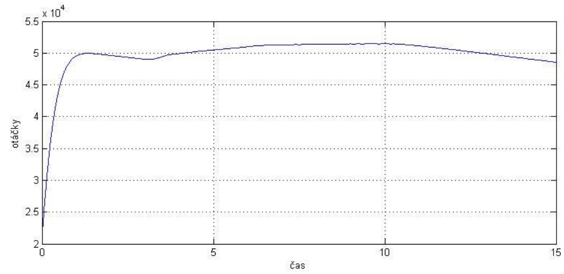


Fig. 9 Change of engine rpm at time

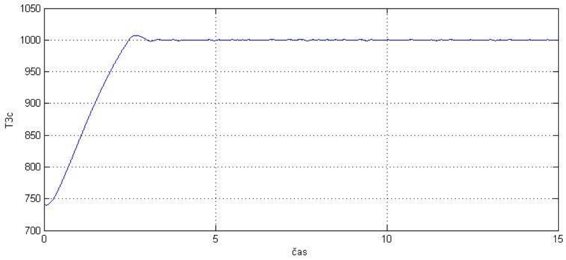


Fig. 10 Change of temperature T3c at time

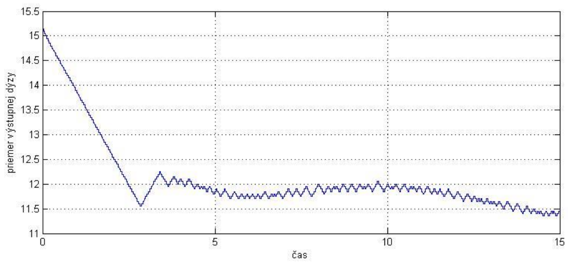


Fig. 11 Change of outlet nozzle diameter at time

6. CALCULATION OF ENGINE THRUST

Thrust of the jet engine, indicated in the Newton (N) is the main parameter characterizing the jet engine as the power unit. It is the result of axial forces affecting on engine´s parts from the flowing air. [1]

The theory of the aircraft engines and simulations on the graph described above clearly showed us that T_3c temperature rising because of using the adjustable nozzle caused thrust gain. However, to be able to see the influence of temperature T_3c to engine thrust in numbers we have to calculate this thrust. It is also necessary, so that we can determine the value of thrust at any time. Knowing all the necessary data of MPM-20 engine we can calculate the thrust from the thermal cycle described in the literature [1]. The resulting thrust will be given by:

$$F_T = F_m \,.\, Q_{pl} \text{ [N]}$$

6.1 Thrust of the MPM-20 engine without controllable nozzles in maximum mode

According to the data I got from Ing. Marian Hocko, PhD for calculating the thermal cycle, the average maximum temperature T_{3c} of MPM-20 engine is 850 ° C, which is the equivalent to 1,123 K. Average fuel consumption Q_p is about 1.28 l min^{-1}. Using the formulas in the thermal cycle and using these values, we will get the final thrust of MPM-20 engine at maximum thrust.

$$F_T = F_m \,.\, Q_{pl} \text{ [N]}$$
$$F_T = 529{,}1735 \text{ N}$$

Comparision of results

Fig. 12 shows the change of temperature T_{3c} at time. On the graph there is change of the temperature T_{3c} at maximum outlet nozzle diameter shown in blue colour. The diameter of the nozzle does not change and remains almost same as the MPM-20 engine had at the time of writing this paper. The temperature reached around 860°C in stable operation of the engine. We can compare this blue line with the green line where the temperature T_3c is maintained at 1000°C by using a regulated outlet nozzle.

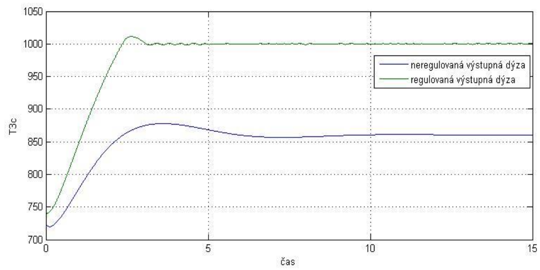


Fig. 12 Change of temperature T_3c at time

Now we can calculate thrust of MPM-20 engine with nozzle opened, where the temperature is 860°C using thermal cycle. We obtained value of F_{T1} thrust.

$$F_{T1} = F_m \,.\, Q_{pl} = 534{,}2 \text{ N}$$

We will use the same calculation for the F_{T2} thrust, where the temperature T_{3c} will be regulated to maximum value of 1000 °C .

$$F_{T2} = F_m \,.\, Q_{pl} = 602{,}74 \text{ N}$$

$$\Delta F_T = F_{T2} - F_{T1} = 68{,}54 \text{ N}$$

Difference between F_{T1} and F_{T2} will give us value of ΔF_T which is value we got by using the program of nozzle regulation in maximum thrust mode. This thrust represents 68.54 N, which represents increase of 12.8%. On the Fig. 13 we can see the progress of thrust at time by changing temperatures T_{3c}.

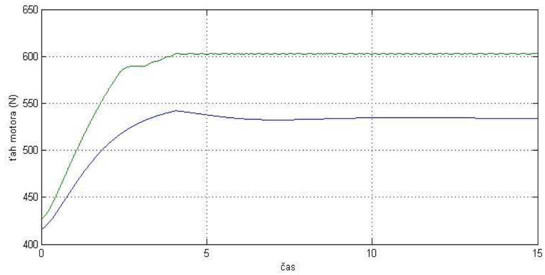


Fig. 13 Change of engine thrust at time

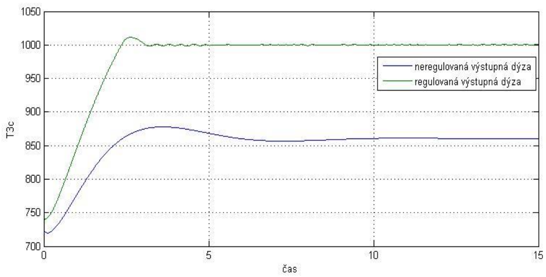


Fig. 14 Change of temperature T_3c at time

CONCLUSION

In order to achieve maximum performance and minimum fuel consumption of modern aircraft engines, these engines must be regulated and optimized. This paper described principle of regulation of the jet engine and designed suitable regulation to gain maximum thrust at any time. The aim of this work showed the benefits of rebuilding the MPM-20 engine from the current engine with one degree of freedom to the engine with two degrees of freedom. From simulations above is obvious that by appropriate management of nozzle regulation we can maintain the maximum possible thrust at given fuel flow. By editing the regulation program of nozzle regulation in the future we can regulate MPM-20 engine to minimum fuel consumtion which is a basic requirement for economic working engine.

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