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RESEARCHES OF THE DYNAMIC CHARACTERISTICS OF THE TURBINE JET ENGINE IN FLIGHT BASED ON ITS GROUND TESTS

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Abstract

Turbine jet engines maintenance (adjustment) actions are performed during standard ground tests, but they are used during the flight. It turns out that the characteristics of the engine determined during the ground tests from the input value "w" introduced by the engine control lever DSS are significantly different from those obtained from disturbance "z" operating in the engine during the aircraft flight. It is noticed, that improvement of the engine control state made by mechanic during aircraft ground tests may cause the deterioration of the engine performance, which is felt by the pilot.

The article presents a method that allows determining the basic characteristics of the engine in flight based only on the signals measured during testing ground. This method is based on measurement the major engine signals n – engine rpm, p_4 – turbine discharge total pressure, p_2 – low pressure compressor inlet, m_p – fuel usage, then the designation of synthetic signals $y=n/p_4$ (which describes the engine output), $u=m_p/p_2$ (describes engine input) and further their own and cross correlation function. Next, the power spectral density functions of these synthetic signals were calculated. Power spectral density functions is a basis to determine the spectral transfer function $H_W(j\omega)$ (during the ground tests) and $H_Z(j\omega)$ (in flight) which are the basis to determine the characteristics (step response) of the turbine jet engine in flight and during ground tests.

Keywords: *jet engine, adjustment, ground tests, engine condition, aircraft engine maintenance*

1. Introduction

Currently, aircraft maintenance are performed during standard ground tests ("w" is the engine input signal), but it's exploitations takes place during its flight when on the engine control system affect additional signal "*z*" – the disturbance. During the engine ground tests, there is only the possibility of introducing to the engine the signal "*w*" (by the engine control lever DSS), and there is no possibility of introducing the disturbance signal "z" (it is dangerous and therefore prohibited), which takes on great significance during the aircraft flight. After conducting the maintenance based on the ground tests aircraft is tested during the "proving flight" (it is performed after every repair). Based on the engine work during test flight its dynamic quality is determined. Engine examination procedures contained ground tests and in-flight tests are very complex, laborious and expensive. It is also dangerous because it is not possible to certainly predict if the well-adjusted engine (adjust based on ground tests from "*w*") will be well –adjusted during the aircraft flight (from disturbance "*z*") [1, 3-7].

Hence, a need to develop such a method of assessing the quality of turbine jet engine operation that allows to determined its characteristics in flight, but based only on the engine signals recorded during its standardized ground, without the need for aircraft inflight.

2. Theoretical basis of the method of assessment of the in-flight aircraft engine maintenance quality based on its ground tests

To examine the turbine jet engine maintenance quality from input "*z*" (during the flight) using its ground tests from input signal "*w*" it is necessary to obtain the transfer functions of each elements of automatic control system. Diagram of automatic control system (UAR) of the aircraft jet engine can be simplified to a standard diagram automatic control system. Scheme of this system is illustrated in Fig. 1.

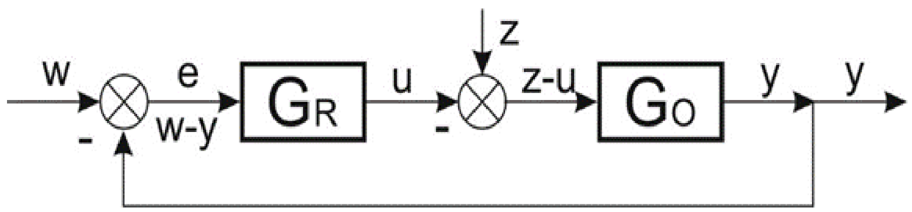

Fig. 1. Scheme of the simplified aircraft engines automatic control system, where: G_R – controller transfer function, G_O – object transfer function, w – input signal delivered by the engine control lever, z – input signal (disturbances), y – output signal (engine rotational speed), e=w-y – input signal for the controller, u – output signal from the controller [4, 6, 7]

Transfer functions from input signals „*w*" and „*z*" may be represented by transfer functions H_W and H_Z:

$$H_W = \frac{G_{OW} G_{RW}}{1 + G_{OW} G_{RW}}, \tag{1}$$

$$H_Z = \frac{G_{OZ}}{1 + G_{OZ} G_{RZ}}, \tag{2}$$

Transfer functions H_W (1) and H_Z (2) are different but after their comparison can be concluded that as a result of multiplication of the transfer function H_W (obtained during ground tests) by the inverse of the controller transfer function G_{RW} (from the same ground tests), it is possible to obtain the transfer function H_{ZW} in the identical form as the transfer function H_Z and which are prepared without the need for in-flight aircraft testing from "*z*" [4-6].

$$H_{ZW} = \frac{G_{OW} G_{RW}}{1 + G_{OW} G_{RW}} \cdot \frac{1}{G_{RW}} = \frac{G_{OW}}{1 + G_{OW} G_{RW}} = H_W \cdot \frac{1}{G_{RW}} = -H_Z\,. \tag{3}$$

In addition, it is concluded that the transfer H_{ZW} and H_W are determined based on the same signals, which are "*y*", "*u*" and "*w*".

These transfer functions can be described by the spectral transfer function (when input signals is w = δ (t) ≈0 and z = δ (t) ≈0).

$$H_W(j\omega)=\frac{\dfrac{S_{yu}}{S_{uu}}\dfrac{S_{u(-y)}}{S_{(-y)(-y)}}}{1+\dfrac{S_{yu}}{S_{uu}}\dfrac{S_{u(-y)}}{S_{(-y)(-y)}}}=\frac{S_{yu}S_{u(-y)}}{S_{uu}S_{(-y)(-y)}+S_{yu}S_{u(-y)}}, \tag{4}$$

$$H_Z(j\omega)=\frac{\dfrac{S_{y(-u)}}{S_{(-u)(-u)}}}{1+\dfrac{S_{y(-u)}}{S_{(-u)(-u)}}\dfrac{S_{uy}}{S_{(-y)(-y)}}}=\frac{S_{(-y)(-y)}S_{y(-u)}}{S_{(-y)(-y)}S_{(-u)(-u)}+S_{uy}S_{y(-u)}}, \tag{5}$$

$$H_{ZW}(j\omega)=\frac{S_{yu}\cancel{S_{u(-y)}}}{S_{uu}S_{(-y)(-y)}+S_{yu}S_{u(-y)}}\cdot\frac{S_{(-y)(-y)}}{\cancel{S_{u(-y)}}}=\frac{S_{yu}S_{(-y)(-y)}}{S_{uu}S_{(-y)(-y)}+S_{yu}S_{u(-y)}}. \tag{6}$$

There is no similarity between the H_W (4) and H_Z (5). However, such a similarity exists between the transfer functions H_W and H_{ZW} (through the transfer function $1/G_R$) and the further between transfer functions H_Z and H_{ZW}. Therefore, by determining transfer function H_{ZW}, we can conclude about H_Z.

Based on formulas (4-6) after transformations can be obtained a relationship between the transfer functions H_Z and H_W, and the signals measured during aircraft ground tests:

$$H_Z=H_W\frac{S_{(-y)(-y)}}{S_{yu}}=\frac{\cancel{S_{yu}}S_{u(-y)}}{S_{(-y)(-y)}S_{uu}+S_{uy}S_{u(-y)}}\cdot\frac{S_{(-y)(-y)}}{\cancel{S_{yu}}}. \tag{7}$$

Thus, by using the transfer function H_{ZW} you can determine a direct correlation between the transfer functions H_Z (model on the fly) and H_W (model engine on the ground). There is therefore possibility to designate engine characteristics when the input signal is disturbance "*z*" (in flight) based on signals registered during ground tests when the input signal is "*w*" delivered by the engine control lever.

3. Determining the engine step responses in-flight using its ground tests

During the turbine jet engine ground tests, many signals are registered (Fig. 1) [7].

The plots of signals registered during sudden deceleration (displacement of the engine control lever from 100% to 0% in a period of 4 sec) and standardized input signals (p_2 – air pressure downstream of the compressor and m_p – differential pressure of the fuel injection) and the output (p_4 – the pressure of the gases in the outlet nozzle, n – engine rotational speed) are shown in Fig. 2.

To simplify the mathematical description of the engine input and output signals are related to each other (Fig. 3):

$$u=m_P/p_2, \tag{8}$$

$$y=n/p_4. \tag{9}$$

Based on this synthetic signals necessary power spectral density functions (S_{xy}) were calculated by means of which it is possible to obtain the real part of spectral transfer functions $H_W(j\omega)$and $H_Z(j\omega)$ (formula 4 and 7) [8].

$$P_W(\omega)=real\left(H_W(j\omega)\right)=real\left(\frac{S_{yu}S_{ue}}{S_{uu}S_{ee}+S_{yu}S_{ue}}\right), \tag{10}$$

$$P_Z(\omega) = real\left(H_Z(j\omega)\right) = real\left(\frac{S_{yu}S_{ee}}{S_{uu}S_{ee} + S_{yu}S_{ue}}\right), \quad (11)$$

where e=-y.

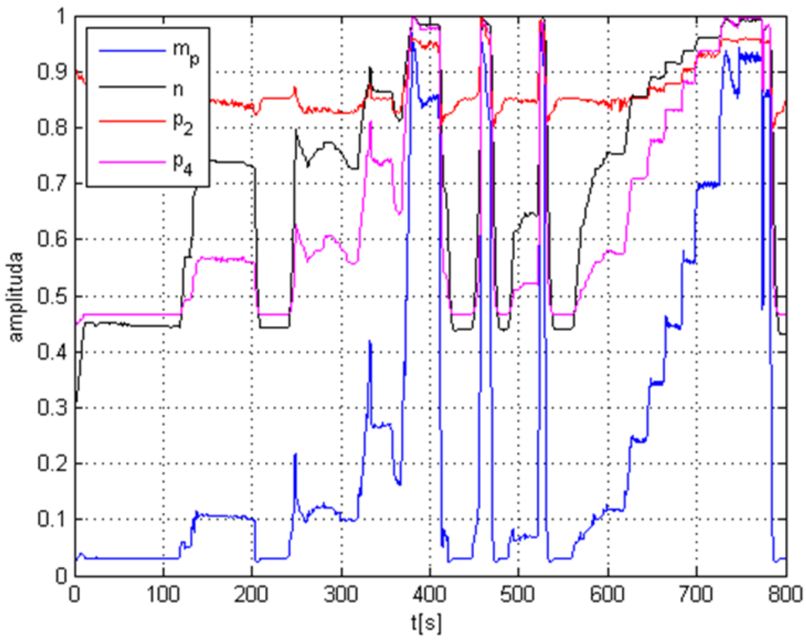

Fig. 2. The plots of standardized signals registered during K15 engine ground tests., where p_2 – input signal, air pressure downstream of the compressor and m_p – input signal, differential pressure of the fuel injection, p_4 – output signal, the pressure of the gases in the outlet nozzle, n – output signal, engine rotational speed

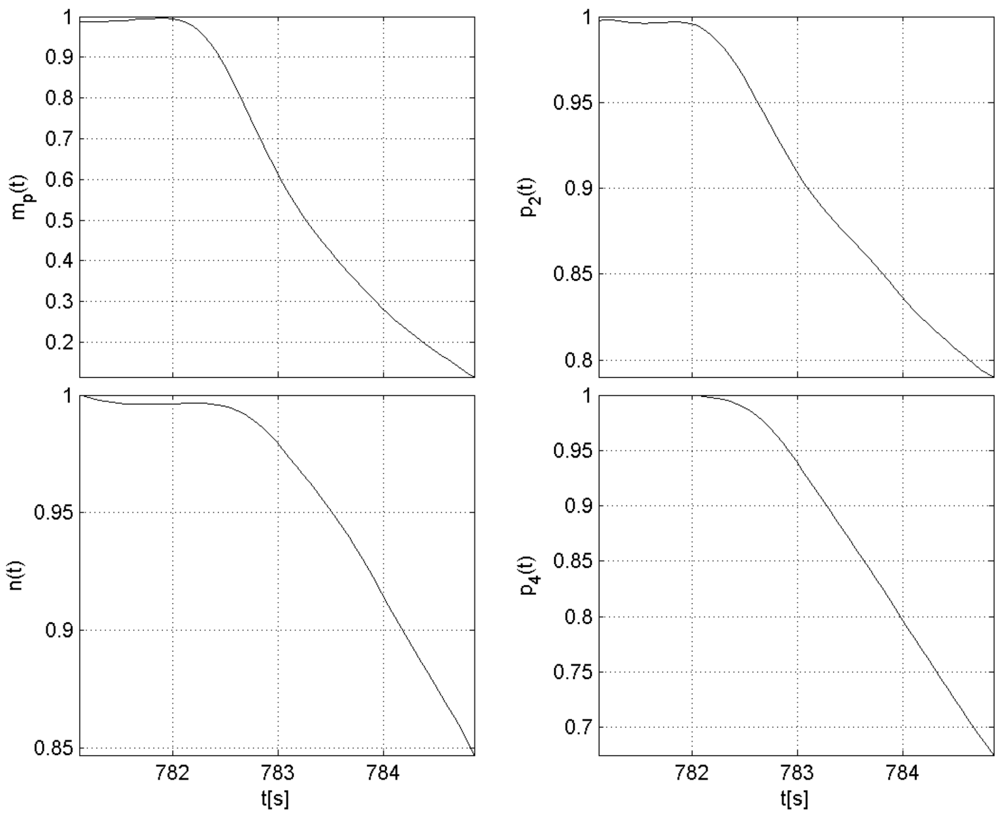

Fig. 3. The plots of standardized signals registered during sudden deceleration

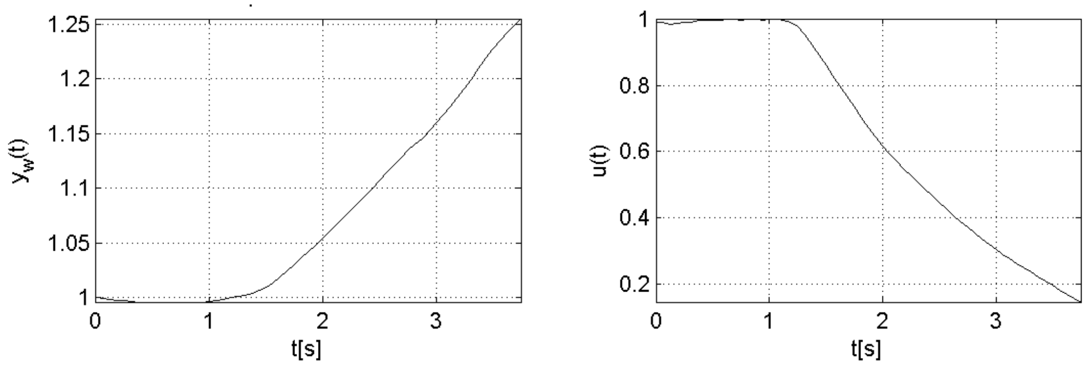

Fig. 4. Synthetic waveforms, where u (t) – signal that describes the engine input, y (t) – signal that describes the engine output

Using the transition from the frequency domain (ω) to time domain (t) according to the formulas (12) and (13) [2, 8], it is possible to designate the determined characteristics of the engine (step response) for the observed moment of time:

$$y_W(t) = \frac{2}{\pi}\int_0^{\omega_n} P_W(\omega)\frac{\sin(\omega t)}{\omega}d\omega, \tag{12}$$

$$y_Z(t) = \frac{2}{\pi}\int_0^{\omega_n} P_Z(\omega)\frac{\sin(\omega t)}{\omega}d\omega. \tag{13}$$

Formulas (12) and (13) allow for the determination of the step response of a turbine jet engine, both its during ground tests (y_w) from the input signal „*w*“ delivered to the controller, as well as during the flight (y_z) when the disturbances „*z*“ affect directly on the object. Their plots for sudden deceleration from Fig. 2 signals were presented in Fig. 4. In Fig. 5 are presented the step response for steady state of the engine work (engine control lever set on 30% in a period of 30 sec).

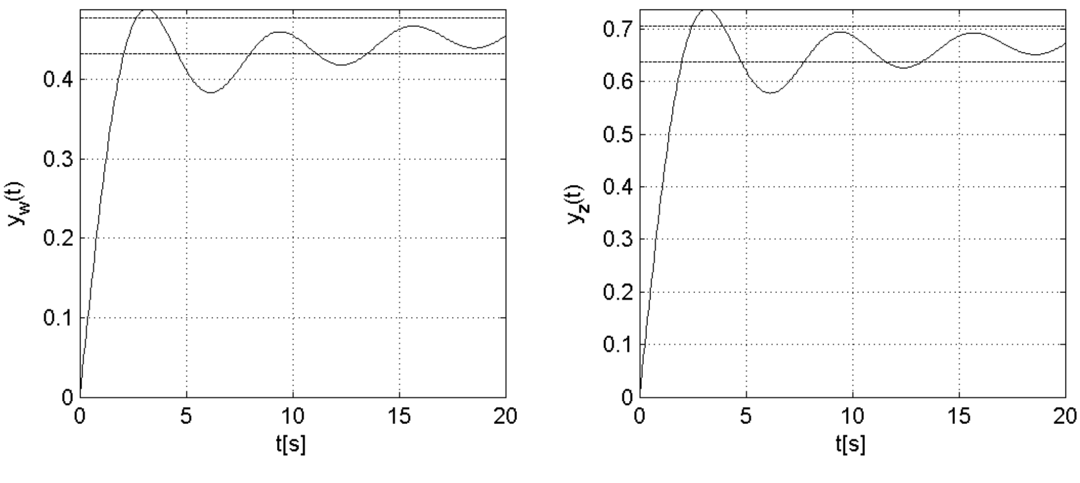

Fig. 5. Step responses of the engine on ground $y_w(t)$ and in-flight $y_z(t)$ for sudden deceleration of the engine

By comparing step responses and their quality indicators obtained for other operating states of the engine work and comparing them with those obtained for the steady state of his work it is possible to describe and assess the state of adjustment.

Obtained in the way engine determined characteristics provide additional information about the quality of its adjustment, which may be used for improving of the adjustment performed during aircraft ground tests.

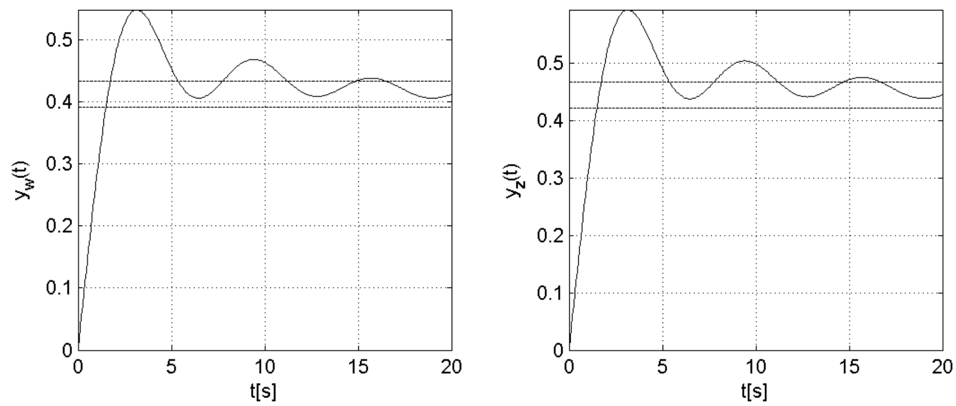

Fig. 6. Step responses of the engine on ground $y_w(t)$ and in-flight $y_z(t)$ for steady state of the engine work.

4. Conclusions

Based on the signals obtained during routine tests carried out on the ground after all repairs of the engine (when input is the signal "*w*" delivered to the controller) is possible to determine the basic engine characteristics during the fly (when signal interference "z" acts directly on the object). The obtained characteristics allows for assessment of the adjustment quality.

This reduces the risk associated with the necessity aircraft test flight performed after engine repair and overhaul carried out to check quality of its operation.

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