UDC 681.5

# THE METHOD OF THE AIRPLANE CONTROL CONDITION EVALUATION IN FLIGHT BASED ON ITS GROUND TESTS

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Air jet engines are adjusted during ground tests carried out periodically, and after each repair. These tests are carried out according to a strictly defined program and on the basis of the responses caused by moving the engine control lever engine is appropriately set (during the ground tests, the disturbances are small and thus their impact is negligible). However, intended use of the engine takes place during its flight. During the flight, the airplane (and thus the engine) is affected by a series of disturbances (eg caused by a tight turn, a blast of air, rocket launches) which often cause unstable engine operation.

The simplified diagram of the engine control is shown in Fig.1[1]

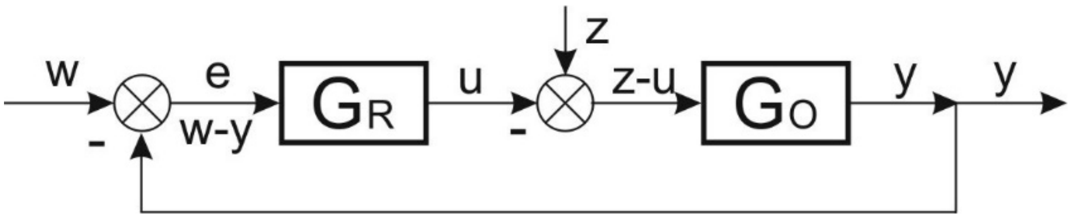


Fig. 1. Scheme of the simplified aircraft engines automatic control system, where: $G_R$ – controller transfer function, $G_O$ – object transfer function, w – input signal delivered by the engine control lever, z – input signal (disturbances), y – output signal (engine rotational speed), e=w-y – input signal for the controller, u – output signal from the controller. [2]

It is known that the "better" (fast engine response, small overshooting) is the engine adjusted during the ground test (when the engine is affected only by „*w*" input), the "worse" it works during the flight (input are both „*w*" and „*z*"). Hence the need to find a method for assessing the state of engine regulation in flight based on its ground tests.

Using signals recorded during a real ground test of the K-15 jet engine: $p_2$ - air pressure after the compressor (input signal), $m_p$ - fuel injection pressure difference (input signal), $p_4$ - gas pressure in the engine outlet nozzle (output signal), $n$ - engine speed (output signal).

It can be assumed that it is correct to replace the input and output signals of the turbine engine speed control system by modified signals:

$$u = mp_2 = m_P / p_2 \qquad (1)$$

$$y = np_4 = n / p_4 \tag{2}$$

$$e = -y \tag{3}$$

The automatic control system from Fig. 1 can be noted using the spectral transfer functions: $H_W$ from input signals „w“ (during the ground tests), and $H_Z$ from input „z“ (during the flight) which are determined using the same signals [1, 2]:

$$H_W = \frac{S_{yu} S_{u(-y)}}{S_{uu} S_{yy} + S_{uy} S_{u(-y)}} , \tag{4}$$

$$H_Z = H_W \frac{S_{yy}}{S_{yu}} = \frac{\cancel{S_{yu}} S_{u(-y)}}{S_{yy} S_{uu} + S_{uy} S_{u(-y)}} \cdot \frac{S_{yy}}{\cancel{S_{yu}}} . \tag{5}$$

There is a direct correlation between the transfer functions $H_Z$ (model on the fly) and $H_W$ (model during the ground tests). 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 [2].

Based on the synthetic signals, the spectral densities of the individual signals power ($S_{xy}$) could be obtained. From which it is easy to get the real part of the spectral transmittances (formulas 6 and 7):

$$P_W(\omega) = real\left(H_W(j\omega)\right) = real\left(\frac{S_{yu} S_{ue}}{S_{uu} S_{ee} + S_{yu} S_{ue}}\right) , \tag{6}$$

$$P_Z(\omega) = real\left(H_Z(j\omega)\right) = real\left(\frac{S_{yu} S_{ee}}{S_{uu} S_{ee} + S_{yu} S_{ue}}\right) . \tag{7}$$

From P(ω) it is possible to designate the determined characteristics of the engine (step response) for the observed moment of time using (8 and 9) formulas [1,2]:

$$y_W(t) = \frac{2}{\pi} \int_0^{\omega_n} P_W(\omega) \frac{\sin(\omega t)}{\omega} d\omega \quad , \tag{8}$$

$$y_Z(t) = \frac{2}{\pi} \int_0^{\omega_n} P_Z(\omega) \frac{\sin(\omega t)}{\omega} d\omega \quad . \tag{9}$$

Formulas (8) and (9) 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. In the above way, the influence of various input and output motor parameters changes (regulation) on the quality of its operation can be studied. Below is presented the obtained signal waveform for simultaneous n and mp change by 5%.

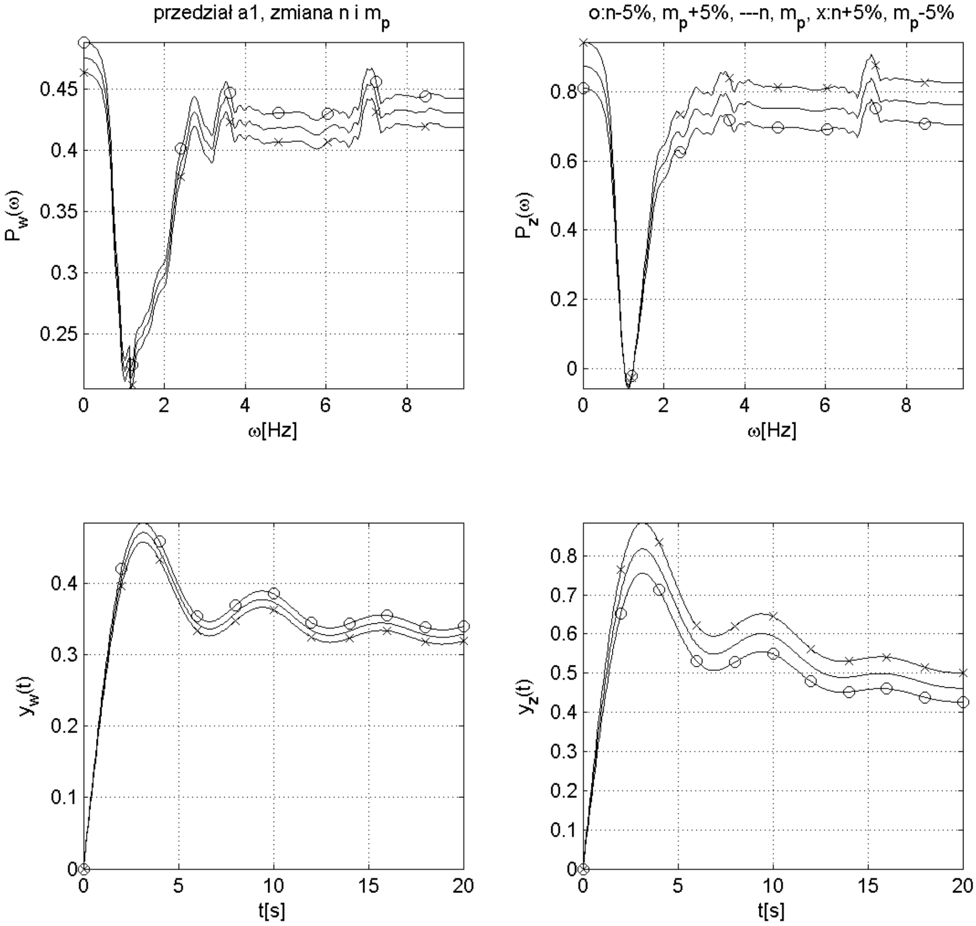


Fig 2. The influence of the changing of „*n*” *and* „$m_p$” signals on step responses from „w” and „z”.

Tests were carried out for various engine operation times, for rapid accelerations "a", decelerations "d" and steady-state work "u".

Tab. 1. Max values of yw and yz changes.

| Changes of parameters | Max values from „*w*” | | | Max values from „*z*” | | |
|---|---|---|---|---|---|---|
| | a | d | u | a | d | u |
| $0.95 \cdot n$, $1.05 \cdot m_p$ | 0,485 | 0,363 | 0,512 | 0,756 | 1,356 | 0,475 |
| $n$, $m_p$ | 0,471 | 0,351 | 0,498 | 0,817 | 1,484 | 0,513 |
| $1.05 \cdot n$, $0.95 \cdot m_p$ | 0,458 | 0,339 | 0,485 | 0,885 | 1,624 | 0,555 |

From the obtained relations between the overshooting, it was confirmed that the properties of the engine in the air are definitely different from the properties of the engine on the ground (this is particularly visible for the sudden deceleration signal „d”- change in DSS deviation from 100% to 0% in 11s).

Tab. 2. Overshooting of yw and yz changes.

| Changes of parameters | Overshooting from „w" | | | Overshooting from „z" | | |
|---|---|---|---|---|---|---|
| | a | d | u | a | d | u |
| $0.95 \cdot n$, $1.05 \cdot m_p$ | 42,94 | 78,48 | 49,17 | 77,30 | 47,77 | 46,20 |
| $n$, $m_p$ | 43,27 | 79,05 | 49,69 | 76,97 | 47,71 | 45,62 |
| $1.05 \cdot n$, $0.95 \cdot m_p$ | 43,58 | 79,58 | 50,18 | 76,65 | 47,65 | 45,07 |

Finally, it is stated that the tests carried out during the ground tests of the engine could provide full information about its properties from the signal „*w*" (follow-up test) and the „*z*" signal (test of resistance to disturbance) in flight. Characteristics from the „*z*" signal allow to unequivocally evaluate its properties during the flight of an airplane without performing an expensive (often dangerous) aircraft flight after its new adjustment.

**References**

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UDC 681.5

## ON STABILIZATION OF NONLINEAR CONTROL SYSTEMS WITH GRÜNWALD-LETNIKOV *h*-DIFFERENCE FRACTIONAL OPERATOR[1]

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***Preliminaries.*** In system theory, in theoretical issues such as, for example, stability and stabilization, representation and identification of nonlinear models, disturbance rejection, a nonlinear dynamic in many cases is represented explicitly as a sum of its Taylor linearization and residual around the equilibrium or working point. Then, results follows from using the known Implicit Function Theorem. Although the concept of the described procedure is simple, but finding the reverse of the Jacobian is not so simple and obvious, it is known to an involved process. In [1] it was proposed another approach based on higher order functions that simplifies the procedure of applying Implicit Function Theorem. This approach was used successfully to examine such properties as controllability and observability of nonlinear discrete-time control systems with fractional difference operators. Now, our goal is to briefly

[1]The work is supported under the program of the Minister of Science and Higher Education under the name" Regional Initiative of Excellence "in 2019 – 2022. Project number 011 / RID / 2018/19