METHOD OF REGULATION CONDITION ASSESSMENT OF TURBINE JET ENGINE IN FLIGHT BASING ON SIGNALS RECORDED DURING GROUND TESTS

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Abstract

During exploitation process operation quality differences may be observed between each particular machine and occurring in exploitation of one machine. These differences result from deviations of realized service process. Turbine jet engine regulation process was realized during ground tests. However, due to varying reactions of engines to external distortions, such as rocket launching, air swirl from another plane etc. as well as lack of possibility of simulation of in-flight conditions on ground (e.g. by partial choking of air intake), a situation may occur in which engine properly regulated on ground may not present sufficient efficiency in flight. Hence, the necessity to assess turbine jet engine regulation condition in flight basing on its ground tests. Research realized on computer models presenting engine operation both in flight and during ground tests indicated that real possibility of engine in flight regulation condition assessment based on its ground tests does exist. As was also noticed, with known input signal "w" and output signal "y_W" recorded during engine ground tests as well as input "e" and output "u" signals from regulator during given test spectral powers and cross spectral powers of signals S_{wyw}, S_{ww}, S_{ee}, S_{eu} may be calculated and thus H_W transfer function describing engine operation during ground test and G_R transfer function describing regulator operation during given test and hence obtain transfer function H_Z describing engine in flight. This grants possibility of regulation condition assessment of turbine jet engine in flight using signals recorded during ground tests.

Keywords: *regulation, computer simulation, turbine jet engine, parametric diagnostics, ground tests*

1. Introduction

Aviation turbine engine with its control system creates a comprehensive system in which the physical processes taking place are determined by an appropriate adjustment program, constructional and exploitation properties of the engine (control system). Of a turbine engine control system may be in accordance with the principles of automation brought to a typical control system (Fig. 1) [1, 4, 6, 11].

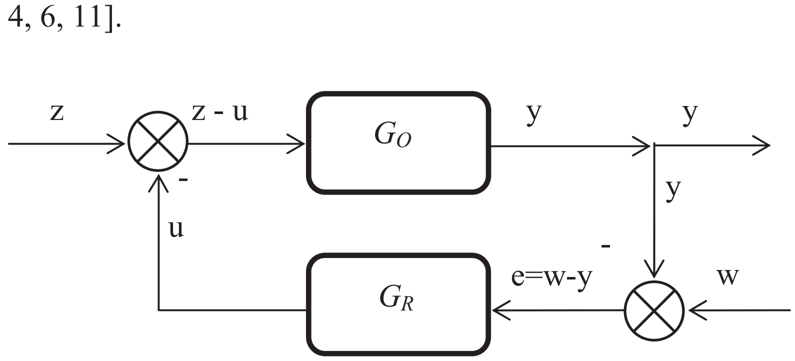

Fig. 1. Block diagram of the aircraft engine control system, where the G_O - transfer function engine, G_R - transfer function controller, y – output signal (e.g. n - rotational speed), e - the error adjustment, u - the command signal z - disturbance, w – engine input signal

Comprehensive research of the control system from Fig. 1 requires the appointment of its characteristics, when the input signal to a system is the set value "*w"* (follow up of the system should be verified - the signal "*y"* should accurate keep up with the signal "*w*") and when the input signal is a variable amount disturbance "*z*" (the resistance of the system on the disturbance should be checked). These characteristics were determined from the transfer functions [5, 7, 9]:

$$H_W = \frac{y}{w} = \frac{G_O \cdot G_R}{1 + G_O \cdot G_R}, \tag{1}$$

$$H_Z = \frac{y}{z} = \frac{G_O}{1 + G_O \cdot G_R}. \tag{2}$$

Transfer function H_W (where the input signal is "*w*") and H_Z (where the input signal is "*z*") are different, so their characteristics will also be different. All of them must be known and possible to practical determine during the engine ground tests.

Operation practice has shown that during the ground tests of the engine signal "*w*" can be easily introduced (via the engine control lever DSS) but it is very difficult to deliver the signal "*z*" (introducing "*z*" to the system is dangerous and therefore prohibited). Additionally, it was noticed that the signal "*z*" during the ground tests is constant and have low power, and therefore it was wrong to abandon the study of the regulation on the basis of transfer function H_Z (2), and limited the study just to transfer function H_W (1). [1, 3]

Disturbance signal "z" (from the environment) is not substantial during the ground tests of the engine, but it becomes very significant importance during the flight, where such phenomena as the firing of missiles, air turbulence, gusts, tight combat turn, air swirl from another plane, etc. generate the interfering signal "*z*" with high power, which can lead to an undesirable flameout of the engine. It is also known that improving of the quality of engine output from "*w*" causes deterioration of the output quality from "*z*" [1, 10].

Hence, there is a need, to determine during the ground tests of the aviation engine not only the characteristics from input value "*w*" but also characteristics from changes in the disturbance "*z*" (Fig. 1).

2. Comprehensive model for aircraft engine testing from "*z*" and "*w*"

Engine ground test should be conducted so that the resultant signal and the relationship between these signals allow obtaining the necessary characteristics from the input signal "*w*" and the disturbance "*z*". After analysing the dependences (1) and (2) that was noticed [6]:

$$H_Z = \frac{y_z}{z} = H_W \cdot \frac{1}{G_R}. \tag{3}$$

Arise from dependence (3) that H_Z (and result from this transmittance its characteristics) can be determined on the basis of identified while ground tests transfer function H_W and the inverse of the controllers transfer function $1/G_R$. Universal block diagram to determine the characteristics from the disturbance "*z*" and from input signal "*w*" was shown in Fig. 2.

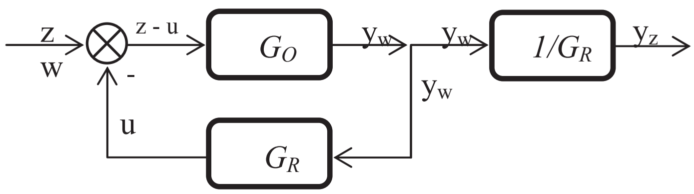

Fig. 2. Block diagram of the aircraft engine control system during the flight

With a registered during ground tests input signals ("*w*" and "*z*"), the controller input signal ("*e*"), the output signal from the controller ("*u*") and output from the object (y_w) shown in Fig. 3 it is possible to calculate the signal (y_z) and transfer function H_Z describing engine during flight.

3. Research methodology for the aircraft engine from "*z*" and "*w*"

The aircraft engines signals recorded during ground are presented in Fig. 3

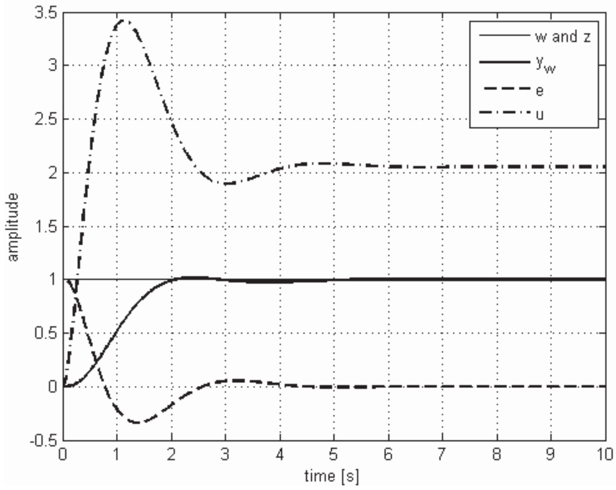

Fig. 3. Automation waveforms available during ground tests.[2]

To determine the $H_W=S_{wyw}/S_{ww}$ and $G_R=S_{eu}/S_{ee}$ only the signals obtained during ground tests were taken into account (Fig. 3). The recorded signals were used to compute their cross and auto correlations [8, 12]:

$$R_{wy_w}(\tau)=\lim_{T\to\infty}\int_0^T w(t)\cdot y_w(t-\tau)dt\,, \tag{4}$$

$$R_{eu}(\tau)=\lim_{T\to\infty}\int_0^T e(t)\cdot u(t-\tau)dt\,, \tag{5}$$

$$R_{ww}(\tau)=\lim_{T\to\infty}\int_0^T w(t)\cdot w(t-\tau)dt\,, \tag{6}$$

$$R_{ee}(\tau)=\lim_{T\to\infty}\int_0^T e(t)\cdot e(t-\tau)dt\,. \tag{7}$$

Waveforms of these signals correlation functions were presented in Fig. 4:

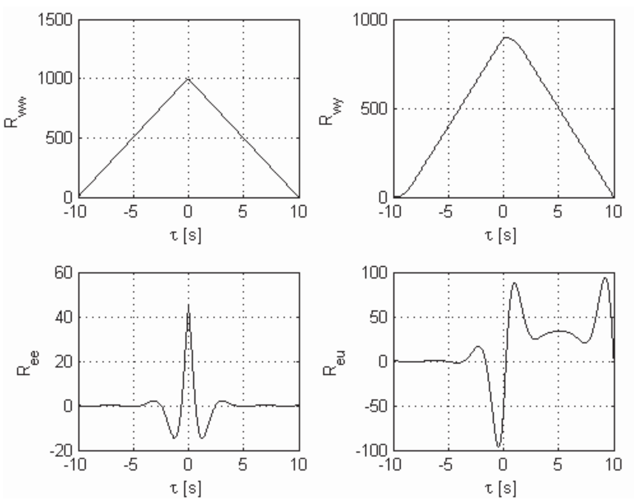

Fig. 4. Waveforms of the autocorrelation and cross correlation functions

The resulting signals of the cross and autocorrelation (Fig. 4.) was been transformed by Fourier transform to get the power spectral density functions [8, 12]:

$$S_{wy_w}(j\omega) = \int_{-\infty}^{+\infty} R_{wy_w}(\tau) e^{-j\omega\tau} d\tau\,, \tag{8}$$

$$S_{eu}(j\omega) = \int_{-\infty}^{+\infty} R_{eu}(\tau) e^{-j\omega\tau} d\tau\,, \tag{9}$$

$$S_{ww}(j\omega) = \int_{-\infty}^{+\infty} R_{ww}(\tau) e^{-j\omega\tau} d\tau\,, \tag{10}$$

$$S_{ee}(j\omega) = \int_{-\infty}^{+\infty} R_{ee}(\tau) e^{-j\omega\tau} d\tau\,. \tag{11}$$

This resulted in auto power spectral density (S_{ee} and S_{ww}) and cross power spectral density (S_{eu} and S_{wyw}) waveforms shown in Fig. 5.

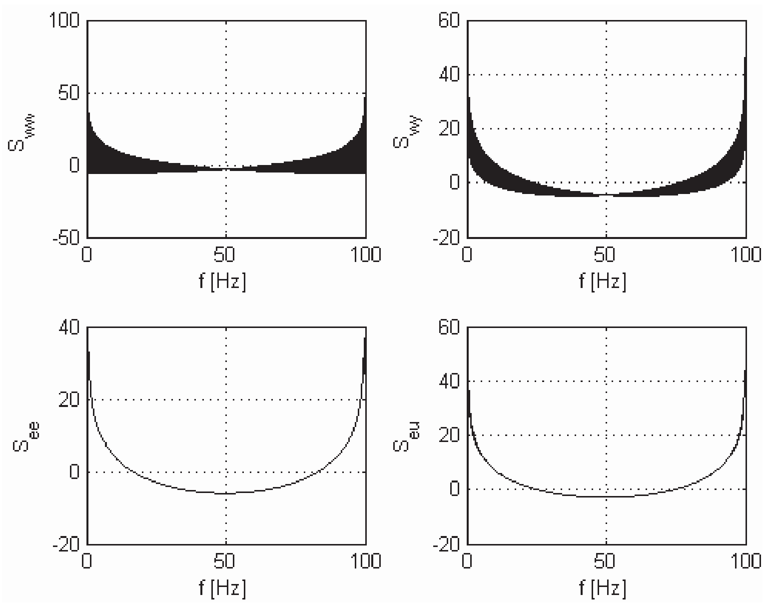

Fig. 5. Waveforms of the auto and cross power spectral density functions

Transfer functions of systems H_W and H_Z, and controller G_R could be represented by the quotient of cross power spectral density and auto spectral power density of input signals.

$$H_W(j\omega) = \frac{S_{wy_w}(j\omega)}{S_{ww}(j\omega)}\,, \tag{12}$$

$$G_R(j\omega) = \frac{S_{eu}(j\omega)}{S_{ee}(j\omega)}\,. \tag{13}$$

According to dependence (3) and using dependences (8) and (9) found that H_Z transfer function could be obtained from the power spectral density of signals recorded during ground tests from the signal "*w*".

$$H_Z(j\omega) = \frac{S_{zy_z}(j\omega)}{S_{zz}(j\omega)} = \frac{S_{wy_w}(j\omega)}{S_{ww}(j\omega)} \cdot \frac{S_{ee}(j\omega)}{S_{eu}(j\omega)}\,, \tag{14}$$

The individual components of the transfer function H_Z like the cross power spectral density S_{zyz}

describing engine signals from input "*z*" (particularly important during flight) according to dependence (3) can also be calculated using only the signals recorded during the ground test (assuming that "*w*" = "*z*").

$$H_Z(j\omega) = \frac{S_{zy_z}(j\omega)}{S_{zz}(j\omega)} = \frac{S_{wy_w}(j\omega)}{S_{ww}(j\omega)} \cdot \frac{S_{ee}(j\omega)}{S_{eu}(j\omega)}. \tag{12}$$

As a result of calculations by dependence (11) cross power spectral density S_{zyR} was obtained, which was compared in Fig. 6 with the cross power spectral density S_{zyz} obtained directly from the waveforms measured during simulation from "z".

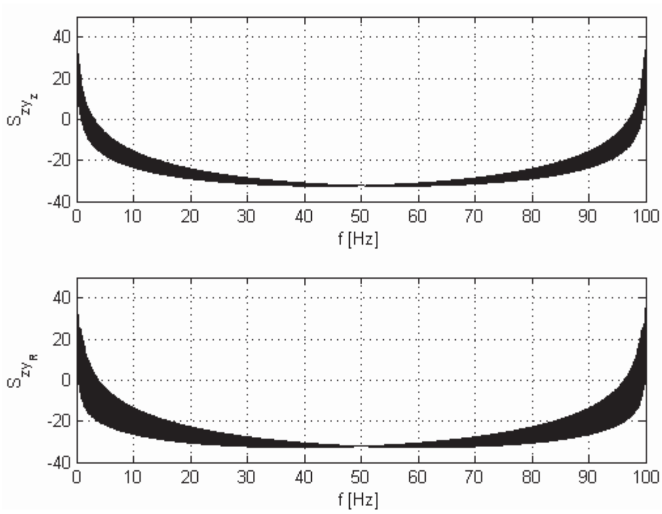

Fig. 6. Cross power spectral density function (S_{zyz}) obtained directly as a result of the system simulation from "z" and the cross power spectral density function (S_{zyR}) which describes the system from "z" too but was obtained from signals recorded during ground tests from "w"

The cross power spectral density function S_{zyw} obtained directly from the waveforms from "*z*" in the simulation and the cross power spectral density function S_{zyR} obtained directly from waveforms measured during "*w*" simulation are similar. This means that it is possible to assess the regulation state of the turbine jet engine during flight based on its ground tests.

Conclusions

Using only the signals waveforms obtained during ground tests it is possible to determine the transfer function, which describes the response signal from disturbance "*z*" (what is important during the flight). This gives the opportunity to assess the state of engine regulation and gives the basis to predict its response to various disturbances during the flight. It may also provide additional information for the pilot about the possible reactions of the engine for individual interferences occurring during the flight and it can greatly facilitate the operation of the airplane during the flight.

Acknowledgements

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