# PREMISES OF PARAMETRICAL ASSESSMENT OF TURBOJET ENGINE IN FLIGHT REGULATION CONDITION DURING GROUND TEST

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**Abstract:** The article presents the theoretical bases of new parametrical method of turbojet engine technical condition assessment. In this method, engine technical condition is described by one (in other methods four are used) comprehensive model (binding engine input – signals $p_2$ and $m_p$ and engine output - $n$ and $p_4$ signals) with unique feature, that engine operation quality during ground tests will provide necessary data on its performance in flight. The changes occurring in turbojet engine during its exploitation will be measurable by comparison of standard model with parameters obtained from experiment (ground test).

**Key words:** Regulation, Computer Simulation, Turbine Jet Engine, Parametric Diagnostics, Ground Tests

## 1. INTRODUCTION

Proper regulation of turbine turbojet engines as well as other objects is a necessary condition for safe usage admission. Currently, in process of engine performance signals courses and their quality indicators values are researched in precisely determined moments during ground tests. Such method of engine performance assessment is unreliable due to differences between environment (temperature, pressure) influencing engine during ground tests and in flight as well as impossibility to imitate noises, usually unknown, affecting engine in flight during ground tests. This may cause a situation where proper regulation during ground tests may not provide sufficient utilitarian value for engine in flight. Hence the necessity of finding new researching method allowing engine performance determined during ground tests to provide data on its performance in flight. One of such methods is comprehensive (simultaneous analysis of four basic signals resulting from engine operation), parametrical (engine performance is described by 32 parameters) method of turbojet engine regulation condition assessment.

## 2. THEORETICAL BASIS OF PARAMETRICAL ASSESSMENT OF AIRCRAFT ENGINE REGULATION CONDITION DURING GROUND TESTS REFLECTING ITS STATE IN FLIGHT

Currently, during aircraft regulation condition assessment, quality indicators of engine signals courses determined during ground tests are of major significance. However these are often inadequate to in flight indicators due to noise and environment changes. Hence the need occurred to supplement the quality indicators of signals courses determined during ground tests with additional parameter – regulation potential, obtained from equation of state binding system operation quality and its technical condition. (Balicki and Szczeciński, 2001; Gosiewski and Paszkowski, 1995; Lindstedt 2002, 2009). Noticeably, this problem may be solved by transforming signals into system parameters such as amplification coefficients, time constants. Obtained parameters allow to assess the value of other, unknown parameters that occur in flight.

Simplified diagram of engine rotational speed regulation system is presented on Fig. 1.

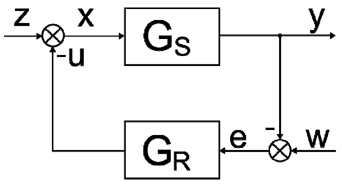

**Fig. 1.** Simplified diagram of aircraft engine regulation system: $G_S$- engine transfer function, $G_R$ – regulator trans function, $w$ – input function, $u$ – signal of influence of regulator onto object, $z$ – interference, $y$ – applied signal (e.g. rotational speed), $x$ – object incentive signal, $e$ – deviation signal

In order to assess the engine operation, transfer functions of closed-loop system for an input function $H_W$ (1) (ground tests) and of closed-loop system for interference $H_Z$ (2) in flight tests (Pełczewski, 1980; Piety, 1998):

$$H_W = \frac{y}{w} = \frac{G_S G_R}{1+G_S G_R} \tag{1}$$

$$H_Z = \frac{y}{z} = \frac{G_S}{1+G_S G_R} \tag{2}$$

Noticeably system ground test transfer function may be multiplied by controller transfer function reciprocal $G_R$ of given test, and thus, by transfer functions determined during ground tests, obtain the transfer function describing engine in flight.

$$H_Z = H_Z \cdot \frac{1}{G_R} \tag{3}$$

This gives base for assessment of regulation conditions of turbine turbojet engine in flight based on its ground tests (Lindstedt 2002, 2009).

## 3. THEORETICAL FUNDAMENTALS FOR JOINT CONSIDERATION OF ENGINE REGULATION CONDITION ASSESSMENT MODELS

Four basic signals $n$ – rotational speed, $p_2$ – pressure behind the compressor, $m_p$- mass intensity of fuel flow, $p_4$ – pressure in engine nozzle, are considered in process of engine regulation condition assessment (Fig. 2) (Lindstedt, 2009; Staniszewski, 1980; Szczeciński, 1965; Szevjakow, 1970).

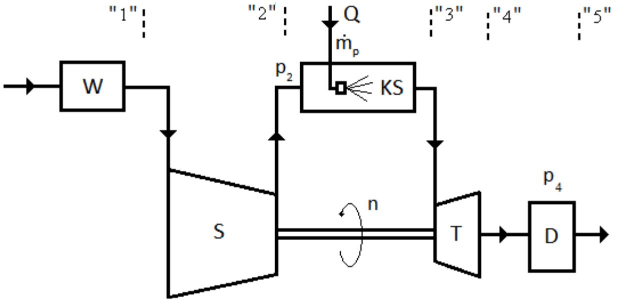

**Fig. 2.** Engine regulation diagram (where W – intake, S – compressor, KS – combustion chamber, T – turbine, D – nozzle, outlet, 1,2,3,4,5 – characteristic sections)

Each relation between main signal, described by following transfer functions, are researched in order to assess engine performance (Balicki, Szczeciński, 2001, Lindstedt, 2002):

$$G_{1m_p} = \frac{\Delta n}{\Delta m_p} \tag{4}$$

$$G_{1p_2} = \frac{\Delta n}{\Delta p_2} \tag{5}$$

$$G_{2m_p} = \frac{\Delta p_4}{\Delta m_p} \tag{6}$$

$$G_{2p_2} = \frac{\Delta p_4}{\Delta p_2} \tag{7}$$

Assumingly, model in form of four transfer functions might be reduced to one comprehensive model with desired feature that allows engine performance determined during ground tests to provide data on its quality in flight.

After removing output signals $\Delta n$ and $\Delta p_4$ from equations (4)÷(7), the following is obtained:

$$G_{1m_p1p_2} = \frac{\Delta p_2}{\Delta m_p} \tag{8}$$

$$G_{2m_p2p_2} = \frac{\Delta p_2}{\Delta m_p} \tag{9}$$

Subsequently, input signals $\Delta m_p$ and $\Delta p_2$ are removed and the following is obtained from equations (4)÷(7) as well:

$$G_{1n1p_4} = \frac{\Delta n}{\Delta p_4} \tag{10}$$

$$G_{2n2p_4} = \frac{\Delta n}{\Delta p_4} \tag{11}$$

In the end, model is created in form of quotient of relations of output signals transform to relation of input signals transform:

$$G_{kompleks}(s) = \frac{G_{1n1p_4}}{G_{1m_p1p_2}} = \frac{G_{2n2p_4}}{G_{2m_p2p_2}} \tag{12}$$

Taking dependences (10) and (12) into consideration, the following is obtained:

$$G_{kompleks}(s) = \frac{\frac{\Delta n}{\Delta p_4}}{\frac{\Delta m_p}{\Delta p_2}} \tag{13}$$

Using inverse Laplace transform following is determined: (Osiowski, 1981; Szabatin, 2000).

$$g_{kompleks}(t) * \Delta p_4 * \Delta p_2 = \Delta n * \Delta m_p \tag{14}$$

As seen from dependences (13), (14), one comprehensive engine model exists that corresponding to 4 classical models applied hitherto in engine regulation condition assessment process. This model is a transfer function (13) or dependence of courses $n$ and $m_p$ tangle (14). Tangle model (14) is difficult to solve. Model (13) is more suitable for further analysis. In case of adopting model in form of transfer function (13), transition can be made from space of variable $s$ to space of frequency $\omega$, hence obtaining ability to analyze signals basing on power densities and cross power densities for signals recorded during engine test.

Transfer function $G_{kompleks}(j\omega)$ argument may be determined from dependence (13):

$$ArgG_{kompleks}(j\omega) = \Delta\varphi_{np_4p_2m_P} = \Delta\varphi_{np_4} - \Delta\varphi_{p_2m_P} \tag{15a}$$

$$ArgG_{kompleks}(j\omega) = Arg\frac{\frac{S_{np_4}}{S_{p_4p_4}}}{\frac{S_{p_2m_p}}{S_{m_pm_p}}} \tag{15b}$$

Subsequently, transfer function $G_{kompleks}(j\omega)$ modulus square may be determined:

$$|G_{kompleks}(j\omega)|^2 = \frac{\frac{S_{nn}}{S_{p_4p_4}}}{\frac{S_{p_2p_2}}{S_{m_pm_p}}} = \frac{A^2_{nnp_4p_4}}{A^2_{p_2p_2m_pm_p}} \tag{16}$$

where: $S$ – power spectral density or cross power spectral density, $A^2(\omega)$ – amplification square, $\varphi(\omega)$ – phase shift.

Signals power S spectral density functions is determined basing on their correlation functions with Fourier transform applied. Therefore, when courses $n(t)$, $p_4(t)$, $p_2(t)$ and $m_p(t)$ are known, determination of their correlation and cross correlation functions and, subsequently, power spectral densities and cross power spectral densities should prove no difficulty. In the end, transfer function $G_{kompleks}(j\omega)$ and, then, signals amplification square $| G_{kompleks}(j\omega) |^2$ might be determined. Similarly, basing on cross power spectral density, phase shift $\Delta\varphi_{np_4p_2m_P}$ is determined ($A^2_{nnp_4p_4}$ and $\Delta\varphi_{np_4p_2m_P}$ being values physically interpretable). (Osiowski, 1981; Szabatin, 2000).

## 4. COMPREHENSIVE, PARAMETRICAL ANALYSIS OF ENGINE REGULATION CONDITION BASING ON ENGINE EXPLOITATION RESEARCH

Recorded courses of input and output signals of turbojet engine are shown in Fig. 3. and Fig. 4. (Pawlak et al., 1996).

Additionally, assumption is made that *DProb* course corresponds with signal $m_p$ course, signal *P4* with signal $p_4$, signal *N* with signal $n$ and *P2* with signal $p_2$.

Ranges for determination of amplification value $| G_{kompleks}(j\omega) |^2$, as well as phase shift $\Delta\varphi_{np_4p_2m_P}$ were determined dividing signal N onto sections as seen in Fig. 5. and Tab. 1.

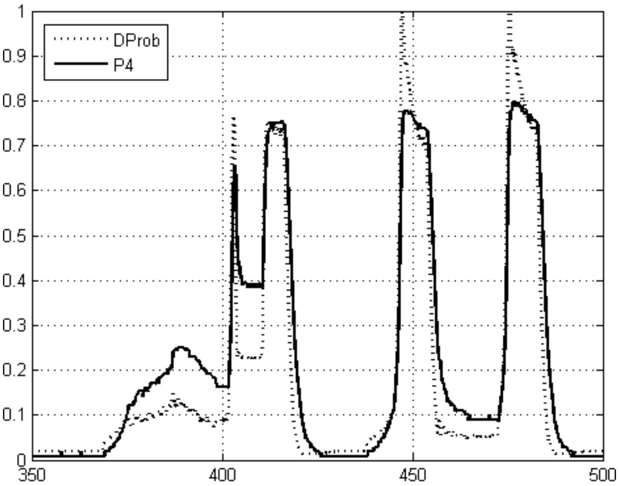

**Fig. 3.** Courses of normalized engine input signals (signal observation time 350 – 500 [s])

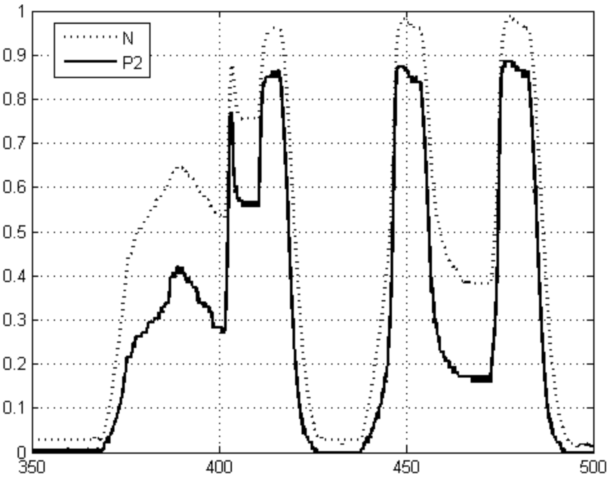

**Fig. 4.** Courses of normalized engine output signals (signal observation time 350 – 500 [s])

**Tab. 1.** Signal *n* ranges for beginning and end of signal course types

| Signal *n* range for the beginning of signal | Signal *n* range for the end of signal | Signal type |
|---|---|---|
| <0,0.33> | (0.33,0.67> | 1 |
| <0,0.33> | (0.67,1> | 2 |
| (0.33,0.67> | <0,0.33> | 3 |
| (0.33,0.67> | (0.67,1> | 4 |
| (0.67,1> | <0,0.33> | 5 |
| (0.67,1> | (0.33,0.67> | 6 |

Recorded characteristics of basic signals *n(t)*, *p₄(t)*, *p₂(t)* i *mₚ(t)* were divided onto sections according to assumptions presented in table 1. Hanning window was put on each of obtained sections. For obtained signal courses autocorrelations and cross correlations of signals *n* and *p₄* as well as *p₂* and mp were calculated. Obtained charts of autocorrelations and cross-correlations were approximated with precision of $R^2>0.995$ (described by determination coefficient) using 4 degree polynomials in general form of:

$$R_{xy}(\tau) = l_4\tau^4 + l_3\tau^3 + l_2\tau^2 + l_1\tau + l_0 \quad (17)$$

$$R_{yy}(\tau) = k_4\tau^4 + k_3\tau^3 + k_2\tau^2 + k_1\tau + k_0 \quad (18)$$

In order to determine function spectral power from obtained autocorrelation and cross-correlation functions, bilateral Fourier transform was used. Subsequently engine models in form of amplification $|G_{kompleks}(j\omega)|^2$ and phase shift $\Delta\varphi_{np_4p_2m_P}$ during ground test were determined in general form of:

$$|G_{kompleks}(j\omega)|_i^2 = \frac{a_{i8}s^8+a_{i7}s^7+a_{i6}s^6+a_{i5}s^5+a_{i4}s^4+a_{i3}s^3+a_{i2}s^2+a_{i1}s+a_{i0}}{b_{i8}s^8+ba_{i7}s^7+b_{i6}s^6+b_{i5}s^5+b_{i4}s^4+b_{i3}s^3+b_{i2}s^2+b_{i1}s+1} \quad (19)$$

$$\Delta\varphi_{np_4p_2m_P}|_i = Arg(\frac{c_{i8}s^8+c_{i7}s^7+c_{i6}s^6+c_{i5}s^5+a_{i4}s^4+a_{i3}s^3+a_{i2}s^2+a_{i1}s+a_{i0}}{b_{i8}s^8+ba_{i7}s^7+b_{i6}s^6+b_{i5}s^5+b_{i4}s^4+b_{i3}s^3+b_{i2}s^2+b_{i1}s+1}) \quad (20)$$

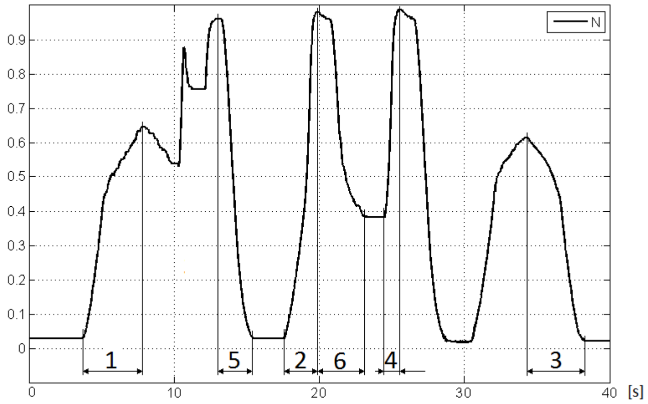

**Fig. 5.** Courses of normalized engine output signals (signal observation time 350 – 500 [s])

Changes occurring in engine during its exploitation may be determined by determining percentage values of each δ parameter (24) deviation from approximate *μ* (21) for each signal course types (Fig. 4.) and comparing them to variability coefficient *v* (22) presented as a percentage and calculated for standard deviations σ(23), 2σ and 3σ.

$$\mu_l = \frac{\sum_{i=1}^{n} x_{il}}{n} \quad (21)$$

$$v_l = \frac{\sigma_l}{\mu_l} \cdot 100\% \quad (22)$$

$$\sigma_l = \sqrt{(x_{il} - \mu_l)^2} \quad (23)$$

$$\delta_{il} = \frac{x_{il}-\mu_l}{\mu_l} \cdot 100\% \quad (24)$$

where: x – parameter a, b, c or d; l – parameter number.

Results are presented as percentage of regulation potential *ϑ* for each parameter.

$$\vartheta_{il} = \frac{v_l-\delta_l}{v_l} \cdot 100\% \quad (25)$$

Results of undertaken research in form of regulation potential *ϑ* of parameters from 5 tests for each of six signal types are presented in Tab. 2. for amplification as well as in Tab. 3. for phase shift.

Engine condition is described by 34 parameters with specific value. For various courses, different configurations and parameter values are obtained. During consecutive tests with identical program, parameters values should remain unchanged. Regulation changes applied during engine ground test, expressed as change of regulator transfer function reciprocal *1/GR* may be introduced into model and ultimately allow determination of engine parameters in flight.

**Tab. 2.** $A^2$ model parameters

| type | nr | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | $a_7$ | $a_8$ | $b_1$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ | $b_6$ | $b_7$ | $b_8$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 43 | 158 | 40 | 166 | 16 | 195 | 104 | 18 | 247 | 2 | 184 | 46 | 81 | 218 | -59 | 82 | 237 |
|  | 2 | 128 | 59 | 160 | 9 | 249 | -67 | 50 | 250 | -43 | 0 | 220 | -50 | 291 | -74 | 139 | 292 | -55 |
|  | 3 | 86 | 114 | 85 | 118 | 71 | 145 | 95 | 69 | 149 | 63 | 129 | 85 | 86 | 150 | 42 | 82 | 156 |
|  | 4 | 271 | -64 | 253 | -33 | 180 | 187 | -27 | 179 | 29 | 245 | -37 | 219 | 34 | 64 | 233 | 35 | 41 |
|  | 5 | -29 | 234 | -38 | 240 | -15 | 40 | 277 | -16 | 118 | 190 | 4 | 201 | 8 | 143 | 145 | 9 | 121 |
| 2 | 1 | 297 | -97 | 297 | -93 | 286 | -84 | 234 | 284 | -94 | 193 | 45 | 64 | 261 | -92 | 276 | 276 | -94 |
|  | 2 | 62 | 153 | 27 | 195 | -3 | 169 | 186 | -6 | 149 | 223 | -43 | 263 | -15 | 148 | 136 | 0 | 147 |
|  | 3 | 40 | 152 | 60 | 117 | 113 | 73 | 99 | 117 | 104 | 9 | 200 | 0 | 152 | 98 | 49 | 134 | 105 |
|  | 4 | 77 | 121 | 79 | 126 | 52 | 183 | -28 | 49 | 173 | 109 | 72 | 164 | 10 | 179 | 51 | 15 | 176 |
|  | 5 | 24 | 171 | 37 | 154 | 52 | 159 | 9 | 56 | 168 | -34 | 226 | 10 | 93 | 167 | -12 | 75 | 167 |
| 3 | 1 | 110 | 85 | 117 | 86 | 69 | 178 | 57 | 65 | 199 | 60 | 138 | 71 | 86 | 205 | 37 | 79 | 200 |
|  | 2 | -14 | 222 | -27 | 227 | 25 | -76 | 261 | 27 | -71 | 249 | -47 | 240 | 7 | -69 | 270 | 15 | -72 |
|  | 3 | 24 | 174 | 29 | 169 | 38 | 51 | 157 | 43 | 79 | 182 | 17 | 186 | 5 | 88 | 159 | 14 | 83 |
|  | 4 | 276 | -72 | 268 | -70 | 297 | 171 | -31 | 298 | 90 | -21 | 225 | -37 | 278 | 77 | 12 | 287 | 89 |
|  | 5 | 103 | 90 | 114 | 87 | 72 | 176 | 56 | 67 | 202 | 30 | 167 | 40 | 123 | 199 | 22 | 106 | 200 |
| 4 | 1 | 299 | -98 | 291 | -68 | 188 | 191 | -57 | 173 | -15 | 202 | 3 | 188 | 37 | 39 | 242 | 35 | 2 |
|  | 2 | 42 | 150 | 64 | 110 | 146 | -13 | 125 | 150 | 54 | 18 | 184 | 14 | 190 | 19 | 34 | 184 | 44 |
|  | 3 | 38 | 173 | 11 | 212 | -36 | 201 | 186 | -34 | 260 | 141 | 55 | 153 | 25 | 244 | 96 | 25 | 258 |
|  | 4 | 58 | 126 | 100 | 59 | 205 | -28 | 33 | 216 | 34 | -51 | 251 | -51 | 249 | 1 | -43 | 253 | 19 |
|  | 5 | 64 | 149 | 35 | 187 | -4 | 149 | 214 | -4 | 168 | 191 | 7 | 196 | -1 | 196 | 171 | 3 | 177 |
| 5 | 1 | 152 | 48 | 152 | 49 | 151 | 151 | 49 | 151 | 49 | 130 | 62 | 144 | 53 | 149 | 50 | 151 | 49 |
|  | 2 | 154 | 46 | 154 | 46 | 155 | 150 | 47 | 153 | 48 | 96 | 81 | 134 | 57 | 149 | 48 | 152 | 48 |
|  | 3 | 149 | 51 | 149 | 51 | 149 | 150 | 51 | 149 | 51 | 157 | 45 | 153 | 48 | 150 | 50 | 149 | 51 |
|  | 4 | -100 | 300 | -100 | 300 | -100 | -100 | 300 | -100 | 300 | -87 | 295 | -99 | 300 | -100 | 300 | -100 | 300 |
|  | 5 | 146 | 54 | 146 | 55 | 145 | 149 | 53 | 147 | 52 | 204 | 16 | 168 | 42 | 151 | 52 | 148 | 52 |
| 6 | 1 | 57 | 181 | 0 | 205 | 30 | -90 | 259 | 19 | -81 | 255 | -53 | 246 | 47 | -84 | 272 | 20 | -81 |
|  | 2 | 45 | 137 | 76 | 119 | 60 | 178 | 71 | 69 | 172 | 45 | 154 | 48 | 116 | 168 | 37 | 130 | 167 |
|  | 3 | 124 | 103 | 77 | 137 | 49 | 88 | 144 | 44 | 63 | 177 | 20 | 188 | -49 | 71 | 154 | -40 | 64 |
|  | 4 | 282 | -92 | 292 | -91 | 299 | 158 | -46 | 296 | 171 | -14 | 215 | -20 | 253 | 175 | 5 | 245 | 181 |
|  | 5 | -8 | 172 | 55 | 130 | 62 | 165 | 73 | 71 | 175 | 37 | 163 | 39 | 133 | 170 | 32 | 144 | 169 |

**Tab. 3.** Regulation potential for $\Delta\phi$ model

| type | nr | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | $a_7$ | $a_8$ | $b_1$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ | $b_6$ | $b_7$ | $b_8$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 27 | 178 | 15 | 188 | 18 | 172 | 70 | 25 | 179 | 89 | 99 | 125 | 34 | 179 | 39 | 39 | 179 |
|  | 2 | 95 | 84 | 152 | -4 | 247 | -29 | 67 | 269 | -5 | -26 | 249 | -84 | 292 | -18 | 102 | 296 | -12 |
|  | 3 | 111 | 85 | 115 | 101 | 51 | 207 | -35 | 46 | 190 | 71 | 115 | 115 | 30 | 193 | 21 | 36 | 193 |
|  | 4 | 279 | -69 | 250 | -17 | 190 | -13 | 270 | 158 | -39 | 282 | -66 | 221 | 105 | -26 | 293 | 88 | -32 |
|  | 5 | -12 | 222 | -32 | 233 | -6 | 163 | 128 | 2 | 175 | 85 | 102 | 122 | 39 | 173 | 45 | 41 | 172 |
| 2 | 1 | 300 | -100 | 300 | -100 | 300 | -100 | 262 | 300 | -100 | 257 | 111 | -87 | 299 | -100 | 276 | 300 | -100 |
|  | 2 | 54 | 150 | 44 | 161 | 40 | 153 | 172 | 44 | 151 | 174 | -84 | 209 | 33 | 152 | 142 | 44 | 151 |
|  | 3 | 47 | 151 | 53 | 142 | 61 | 142 | 19 | 58 | 145 | -7 | 215 | 100 | 68 | 143 | 5 | 59 | 145 |
|  | 4 | 54 | 146 | 54 | 147 | 51 | 152 | 28 | 49 | 151 | 56 | 102 | 147 | 49 | 152 | 56 | 48 | 152 |
|  | 5 | 46 | 153 | 48 | 150 | 49 | 153 | 19 | 49 | 152 | 20 | 155 | 131 | 51 | 154 | 21 | 49 | 152 |
| 3 | 1 | 100 | 94 | 109 | 94 | 64 | 180 | 58 | 62 | 191 | 69 | 125 | 89 | 52 | 192 | 41 | 47 | 190 |
|  | 2 | -15 | 228 | -37 | 237 | 20 | -93 | 280 | 24 | -81 | 248 | -42 | 222 | 87 | -81 | 284 | 92 | -82 |
|  | 3 | 45 | 150 | 54 | 144 | 47 | 103 | 119 | 49 | 128 | 176 | 20 | 192 | -15 | 136 | 129 | -2 | 129 |
|  | 4 | 283 | -76 | 271 | -71 | 297 | 141 | -18 | 298 | 75 | -32 | 240 | -57 | 285 | 71 | 17 | 290 | 77 |
|  | 5 | 87 | 104 | 103 | 96 | 72 | 169 | 61 | 68 | 187 | 39 | 157 | 55 | 91 | 183 | 30 | 74 | 186 |
| 4 | 1 | 300 | -98 | 284 | -44 | 169 | 91 | 114 | 121 | -44 | 241 | -39 | 233 | -10 | 22 | 263 | -4 | -14 |
|  | 2 | 54 | 134 | 85 | 84 | 150 | 32 | 33 | 162 | 90 | 22 | 179 | 19 | 184 | 40 | 34 | 176 | 75 |
|  | 3 | 42 | 174 | 4 | 219 | -31 | 251 | 177 | -23 | 248 | 127 | 70 | 138 | 38 | 261 | 95 | 36 | 255 |
|  | 4 | 43 | 132 | 108 | 36 | 219 | -36 | -52 | 242 | 43 | -43 | 244 | -46 | 251 | 4 | -32 | 258 | 14 |
|  | 5 | 61 | 157 | 19 | 204 | -7 | 162 | 228 | -2 | 164 | 153 | 46 | 156 | 36 | 172 | 139 | 34 | 169 |
| 5 | 1 | 60 | 141 | 58 | 144 | 56 | 52 | 148 | 86 | 111 | 43 | 156 | 45 | 153 | 49 | 150 | 86 | 112 |
|  | 2 | 69 | 130 | 71 | 127 | 90 | 47 | 139 | 90 | 109 | 11 | 180 | 30 | 161 | 48 | 145 | 88 | 110 |
|  | 3 | 43 | 156 | 45 | 155 | 46 | 47 | 153 | 85 | 113 | 56 | 146 | 52 | 149 | 50 | 151 | 85 | 113 |
|  | 4 | 298 | -98 | 298 | -98 | 294 | 300 | -100 | 155 | 53 | 292 | -96 | 298 | -99 | 300 | -100 | 158 | 50 |
|  | 5 | 29 | 171 | 29 | 173 | 14 | 53 | 159 | 83 | 114 | 97 | 114 | 75 | 137 | 54 | 154 | 83 | 115 |
| 6 | 1 | 64 | 181 | -5 | 213 | 14 | -79 | 259 | 0 | -76 | 237 | -33 | 219 | 145 | -78 | 263 | 130 | -76 |
|  | 2 | 34 | 141 | 75 | 118 | 60 | 174 | 67 | 72 | 170 | 87 | 110 | 104 | -12 | 175 | 51 | 8 | 166 |
|  | 3 | 93 | 129 | 58 | 150 | 46 | 59 | 154 | 43 | 52 | 179 | 18 | 188 | 10 | 56 | 164 | -11 | 52 |
|  | 4 | 293 | -97 | 291 | -85 | 295 | 178 | -36 | 289 | 178 | -47 | 250 | -59 | 265 | 176 | -11 | 269 | 187 |
|  | 5 | 16 | 145 | 81 | 105 | 84 | 169 | 56 | 96 | 175 | 44 | 156 | 48 | 91 | 170 | 33 | 104 | 170 |

## 5. SUMMARY

Comprehensive model for turbojet engine regulation condition assessment was executed. This model allows calculating amplification $|G_{kompleks}(j\omega)|^2$ and phase Shift $\Delta\varphi_{np_4p_2m_P}$, that may be physically interpreted. Engine condition is described by 34 parameters of specific value, assuming various configurations for different ground tests signal courses. Obtained parameters present regulation condition of turbojet engine. Changes in engine occurring during its exploitation are expressed as parameters $|G_{kompleks}(j\omega)|^2$ and $\Delta\varphi_{np_4p_2m_P}$ changes and by changes of regulator adjustment. Parameters of ground model and regulations may be the basis to determine engine in flight model according to dependence $H_Z=H_W \cdot 1/G_R$.

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