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APPLICATION OF FLIGHT DATA FOR DIAGNOSTIC PURPOSES

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Abstract

The three types of fully electronic flight-data recorders and evaluating systems have been designed for a last years, in Hungary.

The paper is offered on the problems arisen in the course of using the flight data recorded by new systems for diagnostic purposes through the identification of the mathematical models of aircraft systems and engines.

The problems occurring in the course of practical application were the following:

- problems of model-formation,
- data processing problems,
- evaluation problems.

The paper gives some theoretical and practical recommendations for solving of these problems.

1. INTRODUCTION

The three types of fully electronic flight-data recorders with computerized display and evaluating systems (DAR-2[1], SIROM[2], TEMES[2]) are designed primary to replace the soviet made optomechanical and digital recorders used on-board of a series civil and military aircraft.

Having the reliable data-processing methods the recorded flight data can be used for diagnostic purposes, too.

There were developed and investigated some different types of mathematical models can be applied for this aims through their identification from the recorded flight data.

The goal of this paper is the demonstration of the problems arisen in the course of creating the mathematical models and their application for diagnostic purposes in the new data recorder and evaluating systems.

During research there were investigated the engines, the automatic pilots and the hydraulic actuators[3,4] of elevators. In this paper the problems are demonstrated on the example of using the data recorded by system DAR-2 for diagnosis of engines.

2. FLIGHT DATA RECORDER DAR-2

2.1. Introductory remarks

In the first stage there was developed a new on-board data acquisition system to aircraft Tu-154 known as DAR-1. Trial testing of this system proved that:

- The instrument is suitable for recording engine parameters reliably and to an accuracy one order of magnitude higher than that of conventional on-board instruments.
- On the basis of more accurate data recording a qualitatively new engine diagnostic system was realized by omitting some parameters and adding a few new ones (e.g. acceleration).
- The new diagnostic system would enable the engine thrust, operating times, and overall consumption during a flight to be determined and measured to a much higher accuracy than before.

Utilizing the experimental results obtained with DAR-1, an improved version, DAR-2, was built for mass production. In actual fact DAR-2 might be considered as a simple on-board computer. It collects and records the parameters indicating the condition of the engines and ensures that these are evaluated in the airline ground processing center. It is based on the present service system of the plane, it does not require any additional detectors. With only slight modifications, it can also be used on other types of planes to replace the old types of data recorders.

2.2. Description of the system

The DAR engine diagnostic data acquisition system[1] was designed to continuously measure and periodically record the main parameters of NK-8-2U aircraft engines and the accompanying flight diagnostic data (Fig. 1). The device is located in the making a subsequent averaging possible.

- Monitoring mode III. and the end of measurements

After data recording is completed, the DAR again monitors the revolution speed of the turbines and the real speed. If the rotation speed of at least two engines falls below 45% or the speed below 200 km/hour, the program will store the actual on-board time (as the end of the engines' operation) and the amount of fuel consumed by each engine from start till standstill.

At the end of each day the data cassette is replaced by an empty cassette and the used cassette is returned to the airport computer center for data read-out. Having been averaged and filtered, the parameters are written into the central database where they are available for any data processing operation.

3. THE MATHEMATICAL MODELS

3.1. General information

The investigation-model[6], in fact, is the adequate representation of the information reflecting the essential characteristics of the real system examined, or the system under design. In this respect, the models to be applied can be classified essentially in five groups of different levels (Fig.2).

level	models	examples
1	semmi-empirical, approximative	description of aerodynamic characteristics
2	static	simple thermodynamic model of engines engines
3	dynamic	description of aircraft's movement
4	unstesdy-state	examination in operation of servomechanisms and the characteristics of flight control e.g. angle of attack
5	stochastic	consideration of stochastic effects

Fig.2. The classification of the models

According to our research there were investigated some models of first three levels. Finally there are the three types of the engine models to be developed with the aim of establishing the technical state identification and diagnostic systems for the aircraft. On the one hand, the engine should be described as a dynamic system. On the other hand, such a model is required which - with the knowledge of the variations in the operational characteristics of the engine - is suitable for the possible close localization with diagnostic purposes of the element giving rise to the variation. While the third model is required for the examination of fuel consumption conditions of the engine.

The models should be developed in a linearized form according to the general rules of model-formation[7] with the principle of application-orientation taken into consideration. In the first case, the principles of the state-space method[8], while in the second one, those of the diagnostic model-formation[5] can be applied conveniently. When forming the third model, either the fuel-consumption equation associated with the torque-equation depending on the technical state of the engine and describing its dynamics is applied, or the approximate, semi-empirical relationships describing only the fuel consumption are used.

3.2. The dynamic model

In a general case, the dynamics of an engine can be described by state vector x depending on the structural and operational characteristics p of engine, the control vector u, the vector of environmental characteristics z and the noise vector ξ:

$$\dot{x}(t) = f(x,u,p,z,t) + \sigma_x(x,t)\xi_x \ , \qquad (1)$$

where t is a operational time and σ is a noise-transfer matrix.

In fact, instead of x(t), an output signal vector y proportional to the former can be measured:

$$y(t) = f(x,u,p,z,t) + \sigma_y(x,t)\xi_y \ . \qquad (2)$$

Instead of (1), (2), their linearized form is used very often:

$$\dot{x}(t) = A(t)x(t) + B(t)u(t) + C(t)z(t) + G_x(t)\xi_x(t) \ , \qquad (3a)$$

$$y(t) = H(t)x(t) + D(t)u(t) + F(t)z(t) + G_y(t)\zeta_y(t), \qquad (3b)$$

where the elements of vectors x, u, z, y are the deviations from the specified initial values of the given characteristics; the elements of matrices A, B, C, D, F, G represent vector p in a hidden form, and they are changing only slowly.

Inasmuch, the matrix elements and z change only slowly with time, and y is independent from u, then set of equation (3) can be written in a more simple and a more widely known form, too:

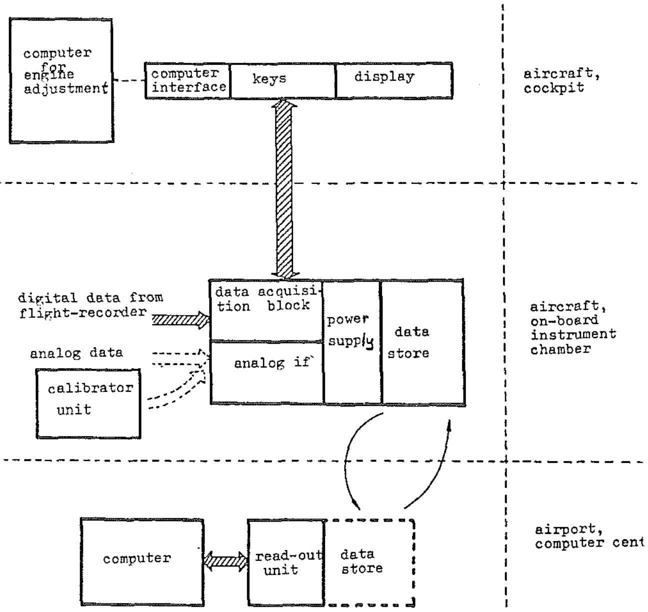


Fig.1. Layout of the on-board diagnostic data acquisition system

instrument rack of the plane, its operation can be monitored and controlled from the cockpit, on the LED display indicators built into the flight engineer's panel.

DAR receives some of the parameters to be measured as digital data from the service data acquisition system MSRP-64[5] and from the control desk, and the rest of the parameters are analog signals from the detectors in the engines.

The measurable and recordable data are the following:

– digital data: identification number of the plane, flight number, date of flight, start-up time of each engine, time of measurement, stop time of each engine, throttle lever position, initial mass;

- analog data: barometric height, indicated air speed, true air speed, Mach number, parameters of each engine (rpm of low-pressure turbine, rpm of high-pressure turbine, temperature of exhaust gas, vibration level, momentary fuel consumption, oil temperature, quantity of fuel consumed up to the time of measurement, overall fuel consumption from start-up to stop), on board power supply, ambient air temperature, angle of pitch, take-off acceleration.

Recording operations can be initiated automatically during take-off ('transient measurement') or by pressing a key during flight ('steady measurement'). DAR provides for the protection of the stored information until it is read out. The easy-to-exchange, semiconductor memory data cassette is periodically changed and taken to the computing center, where the measurement data are read into a computer via a cassette interface and a standard (V-24) serial line.

The diagnostic data acquisition system can also be connected on-line to a computer on board the plane. This real-time data transfer (together with a suitable program) enables more rapid and accurate adjustment of the engines.

Calibration of the data acquisition block takes place by means of a calibrator connected to the instrument instead of signal source outputs during ground control. The calibration program displays the serial number of the uncalibrated measuring channels.

2.3 Data collection

The hardware lay-out, the detailed description of operation the environmental conditions and reliability of the developed system is discussed in the ref. 1.

The system DAR can be operated in modes:

- Initial data collection

Upon switch on, the system performs self-testing and records the angle of pitch and the signal of the X-axis accelerometer from the high-accuracy gyroscope of the artificial horizon in the cassette.

- Monitoring mode I.

The software program monitors the engines' rotation speed and the true air speed. If the revolution of the high pressure turbines in at least two engines exceeds 50% and the speed is more than 200 km/hour (i.e. the plane takes off), the on-board time and the initial total mass previously set on the control panel are recorded as initial operational data of the engines.Monitoring of the acceleration is then started and in the meantime the DAR system continuously summarizes the momentary fuel consumption of the engines until touch-down.

- Dynamic measurements

If the acceleration reaches 0.125 g (this only occurs during take-off) during the subsequent 7 seconds DAR will record the acceleration value 200 times, the engine parameters 20 times and the ambient air temperature and pressure once (transient measurement).

- Monitoring mode II.

The program monitors the height and speed threshold values of 2000 m and 600 km/hour, respectively.

- Static measurements

After the threshold values have been reached, data recording can be started at any time by pressing the pushbutton. It is for the flight engineer to decide on the appropriate flight situation. During the recording, all the above listed flight data and engine parameters are written into the cassette eight times, thereby

$$x(t) = A\ x(t) + B\ u(t) + G_x\ \xi_x(t)\ , \qquad (4a)$$

$$y(t) = H\ x(t) + G_y\ \zeta_y(t)\ . \qquad (4b)$$

The deterministic dynamic model of engine NK-8-2U was developed and investigated by Sánta[10].

3.3. The static model

The mathematical model to be used when processing the static measurement data is contained in equations:

$$f(y) = \Phi(x) \qquad (5)$$

which is written on the basis of physical connections between measurable (external) characteristics y, and unmeasurable (internal) characteristics x describing the technical state. The Diagnostic model consits of the linearized functional relationships occurring between the measurable (y), and the non-measurable (x) characteristics, which nevertheless describe the state of the system elements:

$$K^{*}\delta y = B^{*}\delta x \qquad (6)$$

where δy and δx contain the relative deviations:

$$\delta y = \frac{y_{meas.} - y_o}{y_o}\ ;\quad \delta x = \frac{x_{meas.} - x_o}{x_o}\ ; \qquad (7)$$

from the etalon (calibrating standard) values (y_o, x_o) corresponding to the diagnostic operational duties, while K^* and B^* are constant matrices consisting of the elements obtained by linearization. The set of equations (6) is called the mathematical diagnostic model of the system examined. It can be seen that provided diagnostic model D^* is known from set of equations

$$\delta y = (K^{*^{-1}}\ B^{*})\ \delta x = D^{*}\ \delta x \qquad (8)$$

then δx can be estimated on the basis of the measurement of δy.

The formation of the diagnostic model can be carried out according to the principles similar to those described in the foregoing, and the following steps should be observed[11]:

- Investigation of construction and operation of the diesel-engine. The engine was disassembled into its functional units.

- Establishment of the non-measurable characteristics (internal ones) describing the state of the individual units.

- Determination of the coverage of measurable characteristics.

- Setting up the relationships and equations giving the connections between the measurable and non-measurable characteristics and the individual functional units with the help of the fundamental physical relationships.

- Linearization of the relationships obtained by the method of matching-point linearization.

- Reduction of the number of linearized equations by re-arrangement and substitutions.

- Re-writing the relationships into the form according to diagnostic model equation.

3.4. Generation of the diagnostic model

During the research there were instructed three mathematical models[12]. One of them was an analitical model generated from geometrical characteristics, the second one was on empirical model examined on the basis of the theoretical and technical data of the engines, and the third one was a statistical model identified on the basis of real operational performance data.

Here we show the generation of the characteristics by second model[12,13,] (Fig.3.) based on the method written in the Ref[14].

The practical relationship drawn on the figures created by experts of Technical University of Budapest[14] from the set of nondimensional characteristics analogical types jet engines.(Fig.4 - 7.) For calculation, the input data were taken from the information given by aircraft producer and guided in the Ref[14]. The used assumptions and the actual calculation process are written in the Ref.[13,14].

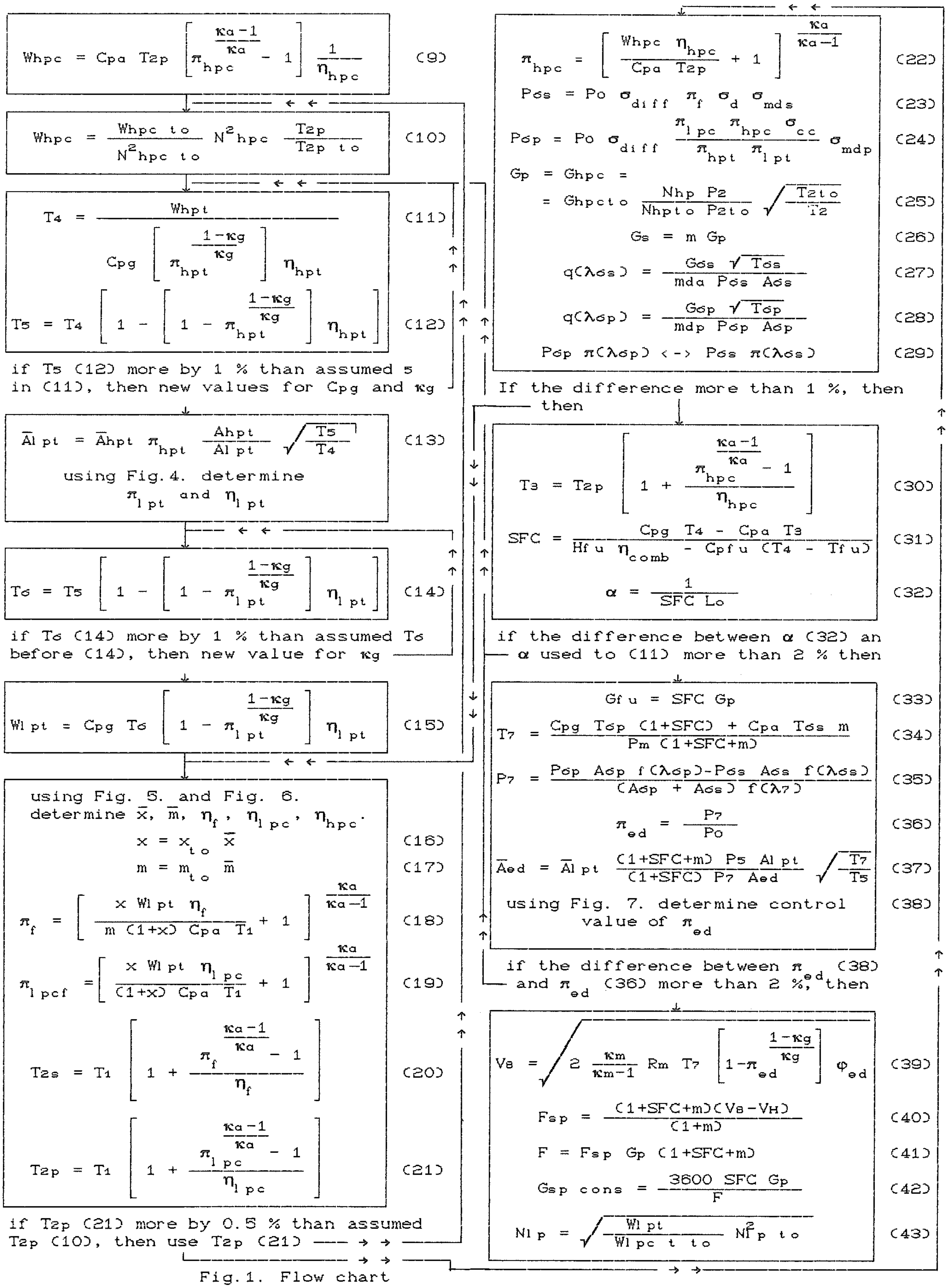
Some results of using the generated model are shown in the tables 1. and 2. These results were applied[12,15,16] in the identification procedure developed for diagnostic purposes.

4. FAULT AND FAILURE DETECTION

4.1. The aim of diagnosis

According to our practice, the possible space of state vector x(t) can be divided into some different parts, into sub-spaces of the

- normal operation, (operation on the prescribed nominal level);
- normal operation with parameter deviations, (operation with anomalies);
- operation with parameter deviations which reduce the operational safety and quality;
- operation with failures which make it needless to stop the operation,
- operation with failures producing accidents.



$$W_{hpc} = C_{pa}\, T_{2p} \left[\pi_{hpc}^{\frac{\kappa a - 1}{\kappa a}} - 1 \right] \frac{1}{\eta_{hpc}} \tag{9}$$

$$W_{hpc} = \frac{W_{hpc\,to}}{N^2_{hpc\,to}}\, N^2_{hpc}\, \frac{T_{2p}}{T_{2p\,to}} \tag{10}$$

$$T_4 = \frac{W_{hpt}}{C_{pg} \left[\pi_{hpt}^{\frac{1-\kappa g}{\kappa g}} \right] \eta_{hpt}} \tag{11}$$

$$T_5 = T_4 \left[1 - \left[1 - \pi_{hpt}^{\frac{1-\kappa g}{\kappa g}} \right] \eta_{hpt} \right] \tag{12}$$

if T5 (12) more by 1 % than assumed 5 in (11), then new values for Cpg and κg

$$\bar{A}_{l\,pt} = \bar{A}_{hpt}\, \pi_{hpt}\, \frac{A_{hpt}}{A_{l\,pt}} \sqrt{\frac{T_5}{T_4}} \tag{13}$$

using Fig. 4. determine $\pi_{l\,pt}$ and $\eta_{l\,pt}$

$$T_6 = T_5 \left[1 - \left[1 - \pi_{l\,pt}^{\frac{1-\kappa g}{\kappa g}} \right] \eta_{l\,pt} \right] \tag{14}$$

if T6 (14) more by 1 % than assumed T6 before (14), then new value for κg

$$W_{l\,pt} = C_{pg}\, T_6 \left[1 - \pi_{l\,pt}^{\frac{1-\kappa g}{\kappa g}} \right] \eta_{l\,pt} \tag{15}$$

using Fig. 5. and Fig. 6. determine $\bar{x}$, $\bar{m}$, η_f, $\eta_{l\,pc}$, η_{hpc}.

$$x = x_{to}\, \bar{x} \tag{16}$$

$$m = m_{to}\, \bar{m} \tag{17}$$

$$\pi_f = \left[\frac{x\, W_{l\,pt}\, \eta_f}{m\,(1+x)\, C_{pa}\, T_1} + 1 \right]^{\frac{\kappa a}{\kappa a - 1}} \tag{18}$$

$$\pi_{l\,pcf} = \left[\frac{x\, W_{l\,pt}\, \eta_{l\,pc}}{(1+x)\, C_{pa}\, T_1} + 1 \right]^{\frac{\kappa a}{\kappa a - 1}} \tag{19}$$

$$T_{2s} = T_1 \left[1 + \frac{\pi_f^{\frac{\kappa a - 1}{\kappa a}} - 1}{\eta_f} \right] \tag{20}$$

$$T_{2p} = T_1 \left[1 + \frac{\pi_{l\,pc}^{\frac{\kappa a - 1}{\kappa a}} - 1}{\eta_{l\,pc}} \right] \tag{21}$$

if T2p (21) more by 0.5 % than assumed T2p (10), then use T2p (21) → →

→ →

$$\pi_{hpc} = \left[\frac{W_{hpc}\, \eta_{hpc}}{C_{pa}\, T_{2p}} + 1 \right]^{\frac{\kappa a}{\kappa a - 1}} \tag{22}$$

$$P_{\sigma s} = P_o\, \sigma_{diff}\, \pi_f\, \sigma_d\, \sigma_{mds} \tag{23}$$

$$P_{\sigma p} = P_o\, \sigma_{diff}\, \frac{\pi_{l\,pc}\, \pi_{hpc}\, \sigma_{cc}}{\pi_{hpt}\, \pi_{l\,pt}}\, \sigma_{mdp} \tag{24}$$

$$G_p = G_{hpc} = G_{hpc\,to}\, \frac{N_{hp}\, P_2}{N_{hp\,to}\, P_{2\,to}} \sqrt{\frac{T_{2\,to}}{T_2}} \tag{25}$$

$$G_s = m\, G_p \tag{26}$$

$$q(\lambda_{\sigma s}) = \frac{G_{\sigma s} \sqrt{T_{\sigma s}}}{m_{da}\, P_{\sigma s}\, A_{\sigma s}} \tag{27}$$

$$q(\lambda_{\sigma p}) = \frac{G_{\sigma p} \sqrt{T_{\sigma p}}}{m_{dp}\, P_{\sigma p}\, A_{\sigma p}} \tag{28}$$

$$P_{\sigma p}\, \pi(\lambda_{\sigma p}) \leftrightarrow P_{\sigma s}\, \pi(\lambda_{\sigma s}) \tag{29}$$

If the difference more than 1 %, then then

$$T_3 = T_{2p} \left[1 + \frac{\pi_{hpc}^{\frac{\kappa a - 1}{\kappa a}} - 1}{\eta_{hpc}} \right] \tag{30}$$

$$SFC = \frac{C_{pg}\, T_4 - C_{pa}\, T_3}{H_{fu}\, \eta_{comb} - C_{pfu}\,(T_4 - T_{fu})} \tag{31}$$

$$\alpha = \frac{1}{SFC\, L_o} \tag{32}$$

if the difference between α (32) an α used to (11) more than 2 % then

$$G_{fu} = SFC\, G_p \tag{33}$$

$$T_7 = \frac{C_{pg}\, T_{\sigma p}\,(1+SFC) + C_{pa}\, T_{\sigma s}\, m}{P_m\,(1+SFC+m)} \tag{34}$$

$$P_7 = \frac{P_{\sigma p}\, A_{\sigma p}\, f(\lambda_{\sigma p}) - P_{\sigma s}\, A_{\sigma s}\, f(\lambda_{\sigma s})}{(A_{\sigma p} + A_{\sigma s})\, f(\lambda_7)} \tag{35}$$

$$\pi_{ed} = \frac{P_7}{P_o} \tag{36}$$

$$\bar{A}_{ed} = \bar{A}_{l\,pt}\, \frac{(1+SFC+m)\, P_5\, A_{l\,pt}}{(1+SFC)\, P_7\, A_{ed}} \sqrt{\frac{T_7}{T_5}} \tag{37}$$

using Fig. 7. determine control value of π_{ed} (38)

if the difference between π_{ed} (38) and π_{ed} (36) more than 2 %, then

$$V_8 = \sqrt{2\, \frac{\kappa m}{\kappa m - 1}\, R_m\, T_7 \left[1 - \pi_{ed}^{\frac{1-\kappa g}{\kappa g}} \right] \varphi_{ed}} \tag{39}$$

$$F_{sp} = \frac{(1+SFC+m)(V_8 - V_H)}{(1+m)} \tag{40}$$

$$F = F_{sp}\, G_p\,(1+SFC+m) \tag{41}$$

$$G_{sp\,cons} = \frac{3600\, SFC\, G_p}{F} \tag{42}$$

$$N_{l\,p} = \sqrt{\frac{W_{l\,pt}}{W_{l\,pc\,t\,to}}\, N^2_{l\,p\,to}} \tag{43}$$

Fig. 1. Flow chart

List of abbreviations used on Fig. 3.

A : flow coefficient,
$\bar{A}$: relative flow coefficient,
Cp : specific heat of given gas,
F : thrust of engine,
f(λ) : gas dynamic function,
G : airflow through a given cross-cut of engine,
Hfu : caloric value of combusted fuel,
Lo : theoretically required volume of air for perfect burning of one unit of fuel mass,
m : bypass ratio of the engine,
m : relative bypass ratio of the engine,
md : gas dynamic function,
N : speed of given rotor,
P : pressure,
q(λ) : gas dynamic function,
SFC : specific fuel consumption,
T : temperature,
V : velocity,
W : specific work (energy for one unit of gas mass),
x : energy split between the primary and secondary flows of engine,
x : relative energy split,
α : coefficient of excessive air flow,
β : 1 + SFC ,
φ : velocity coefficient,
κ : adiabatic exponent of given gas,
π : pressure ratio,
π(λ) : gas dynamic function,
σ : pressure loss ratio of given part of engine,
η : efficiency.

List of indices used on Fig. 3.

o : section before the diffuser,
1 : cross-section before the fan,
2 : cross-section after the fan,
3 : cross-section after low pressure compressor,
4 : cross-section before the high pressure turbine,
5 : cross-section before the low pressure turbine,
6 : cross-section after the low pressure turbine,
7 : cross-cut after the mixing duct,
8 : cross-cut after the exhaust duct,
a : air,
cc : combustion chamber,
comb : parameter related to combustion of fuel,
cons : parameter related to fuel consumption,
d : duct of secondary flow,
diff : diffusor,
ed : cross-section at exhaust duct,
f : fan,
fu : fuel,
g : gas,
H : flight altitude,
hp : high pressure,
hpc : high pressure compressor,
hpt : high pressure turbine,
lp : low pressure,
lpc : low pressure compressor,
lpt : low pressure turbine,
m : mixed gas,
mdp : mixing duct from primery flow side,
mds : mixing duct from secondary flow side,
p : parameter of primery flow,
s : parameter of secondary flow,
sp : specific parameter,
t : total,
to : take-off parameter.

Table No.1. Results by the model mentioned

The sensitivity matrix of ambient parameters [Element (1;1) here means: $\delta\eta_{lpc}/\delta M$]					
i/j	δM	δT_a	δP_a	δF_{fuel}	$\delta\eta_{hpc}$
$\delta\eta_{lpc}$	0.3073	0.1799	0	0.7948	2.1345
δT_5	0.2479	1.0228	0	0.2147	1.8943
δG_{cons}	0.3897	−0.4567	0	−0.5678	4.6789

The sensitivity matrices of inner parameters					
i/j	$\delta\eta_f$	$\delta\eta_{lpc}$	$\delta\eta_{hpc}$	$\delta\eta_{comb}$	$\delta\sigma_{cc}$
$\delta\Pi_{lpc}$	0.6616	−0.5067	−0.2385	0.2345	−0.2066
δT_6	0.1307	−0.9850	−0.1917	0.0943	−0.4135
δG_{cons}	−0.5809	−0.4425	0.5393	−0.1052	0.0189
i/j	$\delta\eta_{hpt}$	$\delta\eta_{lpt}$	$\delta\delta_{duct}$	$\delta\delta_{mdo}$	$\delta\sigma_{mdi}$
$\delta\Pi_{lpc}$	−0.7334	0.7431	0.8825	0.7934	−0.2136
δT_6	−1.5743	−0.1071	0.1744	0.1391	−0.3715
δG_{cons}	−2.8793	−0.1657	−0.7751	−0.5224	0.1579

Table No. 2. the elements of diagnoctic matrice D^*

i/j	δM	δTo	δPo	δHfu	δNlp	δNhp	δTσp	δGsp cons
$\delta\pi_f$	0.7904	-0.3539	0.4883	-0.7659	-1.1107	-0.0750	-0.9216	0.7669
$\delta\eta_f$	0.2158	-0.0482	0.3415	-0.2123	-0.1386	-0.4903	-0.2181	0.2127
$\delta\pi_{lpc}$	1.1674	-0.3943	1.1129	-1.1400	-0.5351	-0.3765	-1.5658	1.1406
$\delta\eta_{lpc}$	0.6856	-0.1111	1.2911	-0.6708	-0.4121	-1.1445	-1.1042	0.6733
$\delta\pi_{hpc}$	0.1500	0.0490	-0.1435	0.1526	0.9595	0.8833	-0.2235	-0.1520
$\delta\eta_{hpc}$	0.2915	0.0579	-.04800	0.2873	-0.3744	0.7218	0.2802	-0.2879
$\delta\pi_{hpt}$	0.1074	0.0610	0.5538	-0.1065	0.9894	0.0695	-0.6318	0.1056
$\delta\eta_{hpt}$	0.0166	0.0384	0.1330	0.0183	-0.1174	0.2903	-0.2656	-0.0175
$\delta\pi_{lpt}$	0.0472	-0.0046	-0.0866	-0.0451	0.1009	0.6513	-0.2718	0.0421
$\delta\eta_{lpt}$	0.2709	-0.0190	0.6472	-0.2607	-0.5536	0.0286	-0.8186	0.2627

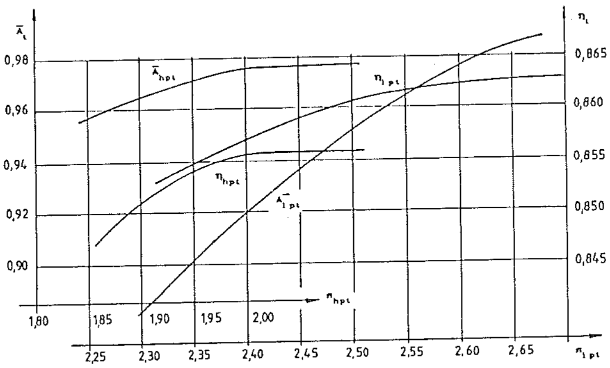


Fig.4. The relative flow coefficients of turbines and efficiencies as functions of their respective pressure ratios

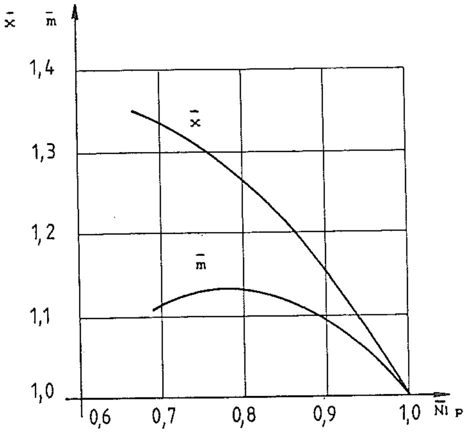


Fig.5. Relative energy split and relative bypass ratio between the engine's primary and secondary flows

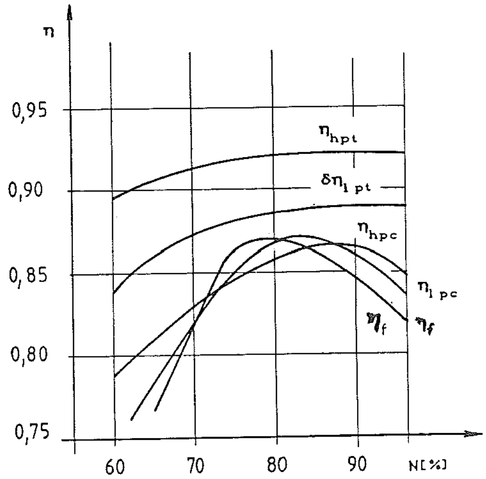


Fig.6. Efficiencies of different part's of engine in dependency on physical speed of respective rotors

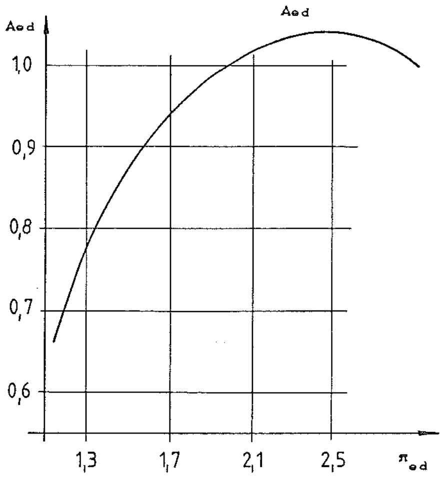


Fig.7. Relative flow coefficient in dependency on pressure ratio

The warning levels of the diagnostic systems should belong to the crossing of the state vector x(t) trough the boundaries of these sub-space.

So, the fault detection in a strict sense can be designed for the detection of these types of states. And the actual failure detection can be connected with the technical system only after the signal given by state detection.

On the other hand, in the course of processing the measurement data for diagnostic purposes, the main objectives are the following:

- approximation of data,
- collected data homologation,
- sensor failures detection,
- prediction of system failures,
- determination of deviations in structural, operational and service characteristics,
- statement of serviceability,
- possibly close localization of the eventual failure (system-diagnostics).

4.2. Fault detection

A fault is appearing if the deviation in the system parameters or in the state vector is greater then the limit calculated on the basis of the prescribed level of the safety and quality.

The fault detection can be realized by using the static or dynamic measurement data collected in the normal operation of the systems

The fault detection recommended in ref.[17] is based on the process model

$$s[k] = p_o^T y[k] + \Delta p^T y[k] + \zeta[k] \,, \qquad (44)$$

where s[k] is a scalar observation, p_o is the parameter vector of the system in the normal state of operation, Δp is the vector of the structure variation depending on the faults or failures.

Parameter vector p_M of the model

$$s_M[k] = p_M^T[k]\, y[k] \tag{45}$$

can be obtained through classical on-line identification procedures based on the following equations

$$p_M[k+1] = p_M[k] - \lambda \frac{e[k]\, W\, y[k]}{y^T[k]\, W\, y[k]} , \tag{46}$$

where λ is a scalar relaxation factor $(0 < \lambda < 1)$, W is a weighting matrix, $e[k]$ is the prediction error

$$e[k] = p_M^T\, y[k] - s[k] . \tag{47}$$

The decision procedure of the fault detection[17] realized through the identified system parameters p_M is based on the hypotheses analysis of the decision theory.

When the environmental characteristics are changing very slowly $(z(t)=\Delta z(t)\approx 0)$, the state estimation observer of the linear dynamic systems type (3,4) is described by vector equation:

$$\hat{x}[k+1] = (A - DC)\, \hat{x}[k] + B\, u[k] - D\, y[k] , \tag{48}$$

where D is the gain matrix of the observer.
The influence of fault type "i" on the state condition can be taken into account in the state space model[18] in the following way:

$$x[k+1] = A\, x[k] + B\, u[k] + L_i\, m_i[k] + G\, \eta_x[k] , \tag{49}$$

where m_i is disturbing characteristics of fault having effect on the state condition, L_i influence matrix of fault "i".

The fault detection can be solved through the design of the gain matrix D based on the following equation:

$$e[k+1] = (A - DC)\, e[k] + L_i\, m_i + (G - D)\, \eta[k] . \tag{50}$$

In principle, gain matrix D should be designed separately for each type of the faults.

The fault detection can be realized by on-line way, too, if the diagnostic matrix D^* in the static diagnostic model (8) is well-defined stable matrix. In this case, the warning level connected with the deviation of the internal characteristics x.

$$\delta x = (D^*)^{-1} \delta y \tag{51}$$

5. THE PROBLEMS

The developed diagnostic models were used in the evaluation of test flights and experimental ones, identification procedures[15,16].

The methods to be applied to the processing of the dynamic and static measurement data differ fundamentally from each other. Since in the course of static measurements, the number of the measured characteristics is usually fewer than that of the characteristics to be determined. Therefore, in such cases, only methods applicable to the localization of the values (of minimum position) belonging to the extreme of the multi-dimensional error-criterion-surface area can be used.

The problems occurring in the course of practical application[13-16,19] were the following:

5.1. Problems of model-formation

- Lack of a-priori information

There is not a sufficient amount of primary information for the models to be formed on the basis of the new aspect, there are no performance data, and characteristics-curves available to reflect the dynamics of jet-engines NK-8-2U on a corresponding level, and there is no information obtained on how the engine's characteristics change as a function of operational conditions, the time of operation and the possible failures. During the research we had been connected with the producer of engines and finally some characteristics of compressors and turbines were given to us. (Fig.8.)

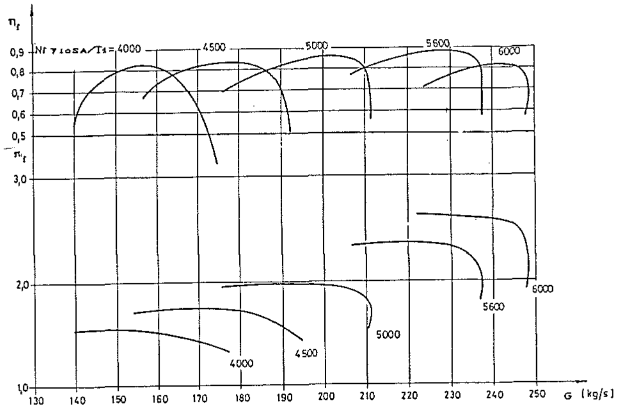


Fig.8. Characteristics of the low pressure compressor given by engine producer

- Incomplete theoretical knowledge

E.g. when forming the mathematical model of jet-engines NK-8-2U, it is unknown to what proportion the energy demand of the low-pressure compressor is shared between the primary and secondary flows, since only one part of the compressor operates in the secondary flow, too. This problem was solved by using the curves shown on Fig.8. generated in Ref.[14].

- Linearizability

The conditions, the limits of the applicable linearization are not clear enough.

- Separability

Linearized equations of the models describing the state of engines are generally separated from the models describing the motion of the aircraft. However, the boundaries and the conditions of such separations are not known well enough.

5.2. Data processing problems

- Accuracy of measurement

The accuracy of the present board data collecting system which was used before developing the new system is not satisfactory, the displays can often contain as much as 5 - 10 % error.

- Discretization

It should be thoroughly examined what discretization and sampling-time belong to the identification of the model. In the present data collecting systems, even the important, dynamically varying characteristics are discretized only with 2 - 4 Hz sampling, which is not sufficient according to our examinations.

- Conjugation

The sampling of the system is performed by successive request, in case the request interval period is long, then the time-differences occurring at the measured values of the individual characteristics should be taken into consideration.

- Measurement noise

Beside the additive stochastic noise aggravating the measurements, also the linear dependence of the single columns of the measurement data matrix-array should also be reckoned with. (Fig.9.)

5.3 Evaluation problems

- Accuracy, reproducibility of identification procedures

Identification procedures involve a great enough number of errors, and even in the case of the same procedure, considerable deviations could be detected in the identified values.

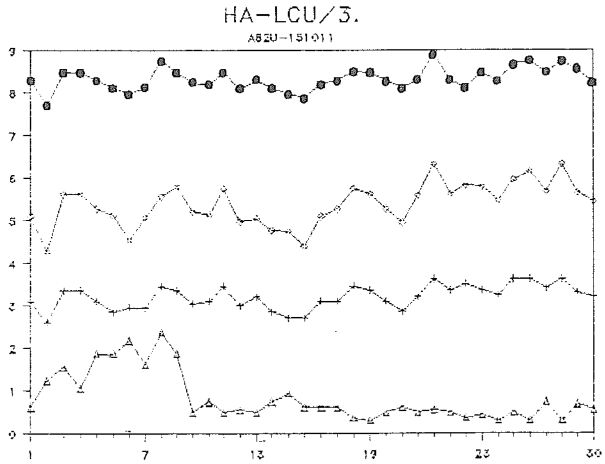


Fig.9. The real converted datameasured parameters of engine (o - temperatura of exhaust gas, , + - speed of high and low pressure rotors, - vibration of forward bearing support)

- Deviations in the parameters of the basic model

It is the propriety especially of the mathematical diagnostic model that due to the maintenance, adjustment, repair or component replacement, the diagnostic matrix elements entering into the model are subject to changes to a measure comparable with the accuracy of the identification procedure. For example, during the operational processes, the characteristics and performance data of jet-engines NK-8-2U can be changed 8-12 % as compared with the nominal, operational documentations and technical specifications. (It can be seen on the Fig. 10., too. The calculated deviations are changed uncontinuously after maintenance of engine.)

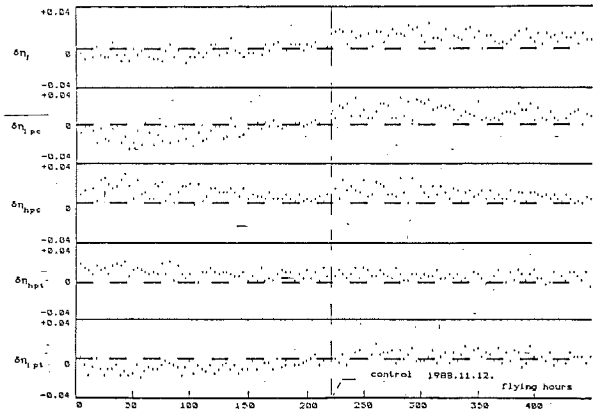


Fig.10. The calculated deviations in the characteristics depend on the flight operational time

- Selection of the basic zone

Especially in case of processing the static measurement data, the values to be identified are searched within the zones given previously, while the procedures investigating the extreme, minimal values of the error criterion, e.g. the gradient method, often run out to certain extreme values of the basic zones, boundaries.

- Diagnostic value

It is especially important for the application of diagnostic purposes that the identified factors of the selected models should have the corresponding diagnostic values.

6. RECOMMENDATIONS

On the basis of our examination results achieved so far, the following recommendations are made for bridging the problems arisen[13-16,19] :

6.1. Theoretical methods

- Imitated experiment with the aim of developing the models to be identified

E.g. to develop the mathematical diagnostic model of type (8) required for the application of DAR system, previously there were developed three mathematical models of the jet-plant, with help of which we tried to compensate the lacking information.

- Preliminary determination of the diagnostic value

Already in the course of developing the models to be identified, the diagnostic value of the factors entering into the model was studied with the help of imitated experiments of both statistical and sensitivity theory types.

6.2. Practical methods

- Development of new systems for the more objective collection, recording and processing of flight information.

- Preliminary, wide-sphere data processing

Filtering the measurement results, detection of linear dependencies, eventual stochastic approximation, homologation of the measurement results.

- Development of new identification procedures.

- Detection, in practice, of the relationships between the variations of the identified factors and the actual technical state.

It is possible only after the more wide-spread application of the methods.

- Application of a duty apt to learn

According to our examinations, the state observation and diagnostic systems on board should, in fact, first learn the object examined, and only later on, they could signalize the deviations from this state of the system learned as a standard one.

7. CONCLUSIONS

In this study, the application of the flight information collected by on-board data recorders for diagnostic purposes is discussed. The mathematical models applicable to testing the operational conditions of jet-engines and determining their operational state are introduced. When investigating the diagnostic and identification applications of the information recorded in the operational testing and collected by the on-board data-collecting system DAR, we studied the applicability of the models recommended.

Here were described the problems aggravating the application of flight information for diagnostic purposes, and were summarized the recommendations contributing to the solutions given to this problem as based upon our multi-year experiences.

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