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MULTICHANNEL COMPUTER AIDED MEASUREMENT OF PRESSURE IN THE AERODYNAMIC EXPERIMENT

En   A significant part of the experimental investigations (EI) in wind tunnels (WT) aimed at simultaneous measurement of air pressure at distributed points as in the WT, and aircraft models (AM) and in jet engines. In this regard, the actual problem is creation of means and methods for simultaneous measurement of pressure as discussed in the work.

The first method. The holes of the selection pressure pneumatic tracks (PT) are connected to the pressure sensor (PS), which are connected to the channels of the measuring system (MS). In this MS apply precision instrumentation programmable filter, communication interface with computer and time measurement for channel ≤40ms. The cost of this MS is high, even for 16 channels measurement interval ≥640ms, which for most of the EI is not acceptable.

The second method is the use of electro-mechanical pneumatic switches (EMPS). For example, in EMPS type PS-180/ 300/ 420 continuously rotating the rotor of the switching node with a phase shift connects PT to PS, synchronously with the time of establishment of pressure measurement is performed.

The third method is the use of mobile pneumatic modules with interface for the transmission of real-time experimental data (ED) in MS. Such devices, for example, can be up to 16 with the number of measured channels and 256.

The proposed unified information-MS (IMS), which can be implemented on different hardware and software platforms (VME, PC/104, MicroPC, etc.).

Processing. Is calculated, sorted and stored value of the absolute and relative pressure pulsations of velocity head. Determine the mean value and standard error. Normal distribution was confirmed by ED Pearson criterion $\chi = 7.13$ at the significance level $\gamma = 0.95$. Statistical reproducibility of ED is confirmed by the criterion of Cochran, assess the homogeneity and error. Is determined by the Reynolds number based on the physical parameters in the WT. The accuracy of the ED algorithm provides operational control of IMS.

The transformation function PS is defined in terms of the polynomial. In difficult cases it is necessary to use *D*-optimal plans experiment.

The coefficients of longitudinal and normal components of aerodynamic force, the coefficient of longitudinal moment, the relative position of the center of pressure, normal and tangential components of aerodynamic forces. The problem is to compute the integral with minimum error. It is recommended to apply the

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Romberg method.

Ru   Изложенные проблемы экспериментальных исследований в аэродинамических трубах направленных на одновременное измерением давления воздуха в распределенных отверстия на моделях летательных аппаратов и в струях двигателей.

Рассмотрена постановка задачи, многоканальные средства, информационно – измерительные системы, измерительные системы, первичная обработка, определение функции преобразования датчиков давления, суммарные характеристики и алгоритмы каждого этапа экспериментальных исследований.

Introduction

Much of the experimental research (ER) in wind tunnels (WT) aimed at simultaneous measurement of air pressure in the apertures distributed in the WT on the models of the aircraft (MA) and in jet engines, the so-called drainage test [1, 2].

For example, MA An-124 (122MC.400.001) had 1136 drainage holes (674 – wing, pylons and gondolas of engines, 317 fuselage, 147 – tail section) and pneumatic road (PR) – copper 2x0,05 and polyvinylchloride tube 3x0,075. Simultaneous pressure measurement in MA provide an electromechanical pneumatic switches (EMPS) [2, 3] (fig. 1, a), and in the jets simulators engines /engines – EMPS and pneumatic modules (fig. 1, b) [3, 4].
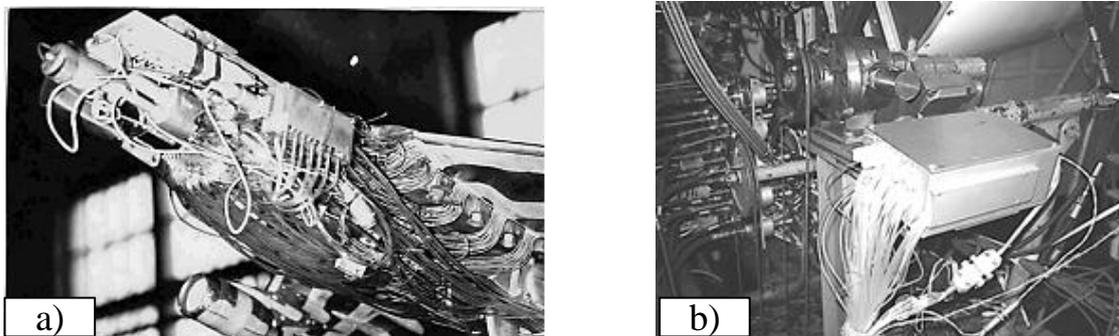

Fig. 1. Examples of simultaneous pressure measurement

Statement of the problem

The basis of ER MA in WT is based on the following algorithm [5]:

$$H_i \to M_i \to P_i \to L_i \to \{D_i\} \to I_i \to R_i \to$$
$$\uparrow \quad \leftarrow \quad M_{i+1} \quad \leftarrow \quad H_{i+1} \quad \leftarrow \quad \downarrow \tag{1}$$

where: H_i – hypothesis/ expected outcome; M_i – option MA; P_i – program ER;

L_i – algorithm processing and analysis of experimental data (ED);

D_i – getting ED; I_i – interpretation of results;

R_i – the criterion of goal achievement.

Actual problem for stages L_i and D_i (1) is creation of means and methods for simultaneous measurement of pressure [1, 4], which is considered in the work.

Multi-channel means

Hole selection pressure through PR are connected with pressure transducers (PT), which are connected to the channels of the measuring system (MS). This scheme has the following disadvantages: a large number of PT; hum and noise in the signals from PT to MS give rise to unacceptable measurement error. Problems are solved by the use of precision measuring devices with a programmable filter, a communication interface with a computer and time measurement for channel ≤40 ms. For example, 34970A /multimeter, 34902A /multiplexer *Agilent Technologies* [6]. The cost of such aircraft is high, even for 16 channels measurement interval ≥640 ms, which for most ER is unacceptable.

Another method is the application of EMPS. For example, EMPS (fig. 2, a) [4] can be used to sequentially connect PT to PR 12 of which two (vacuum, atmosphere) is needed to determine the current transformation function PT and increase accuracy of measurement. Disadvantages are: long 10-15m PR cha catfish establishing a pressure ≥300ms; cycle measurement on channel ≥4c (slow processes); the control of the solenoid valves PR switching is performed using high-power signals (24V, 3A) that heat the PT and change their transform function (not normalized scatter of ≈ 20%), creating substantial measurement error; the extremely low reliability of the solenoid valves.

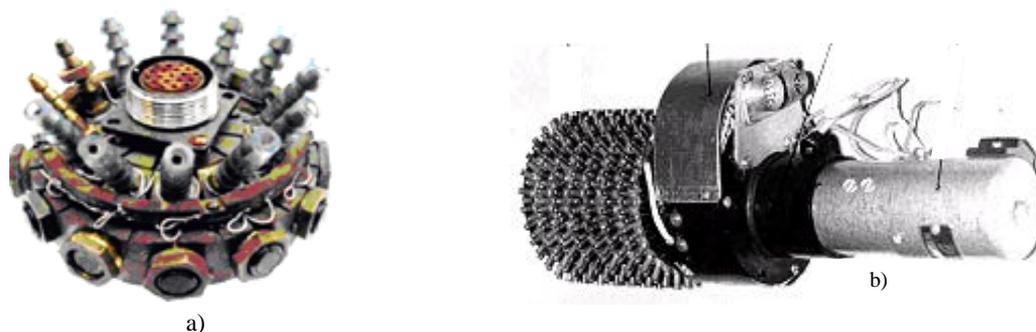a)   b)

Fig. 2. Electromechanical pneumatic switches

Series EMPS type PS-180/ 300/ 420 [2, 3] (fig. 2, b) has the following particularities: a continuous rotation of the rotor of the switching node; node koutouki with phase shift connects PR to 4 (PS-180) or 7 (PS-300/ 420) PT; simultaneously connecting the PR to the PT and taking into account the settling time of the pressure measurement is performed; the output signals from РТ ДМИ(induction pressure sensors)-01/ 03/ 0,6 [7] enhanced to level +5V, output levels of the РТ ИКД (measurement systems pressure) +9.5V [8]; in series/

parallel to run EMPS; served static control (automatic deliverer) -500±1 kg/m^2 pressure with MA.

Unit PT type ИКД (≤20) equipped at the required pressure values from 0.016 to 6 kg/cm^2 in the measurements according to the scheme "point to point". The number of holes measuring up to 1170. РТ ИКД-0,04 applied to determine the difference between static in forkner and atmospheric pressure in the working part of the WT with an error of ≤0.6 kg/m^2. The measuring range of the pressure drops: the MA from -1800 to +200 kg/m^2 with an error of ≤3 kg/m^2; in the jets simulators engines from -200 to +5000 kg/m^2 with an error of ≤10 kg/m^2.

Note that when measuring the pressure in the working part of the WT it is necessary to fulfill two contradictory requirements of minimizing: PR lengths to reduce the settling time of the pressure and momentum signals; the distance from PT to MS to reduce noise and interference in communication lines.

In such circumstances it is advisable to use mobile multi-channel pressure gauges (MCPG) with the interface for transmission in real time ED to MS in the sun and can be installed in the WT or inside /outside the MA. For example, МИД-10 (multi-channel pressure meter) (fig. 3, a) and modification of the МИД-10-1 (fig. 3, b) [4].

a)   b)   c)

Fig. 3. Mobile multi-channel pressure gauges

МИД-10 /10-1 have a sealed housing with fittings for connection to 10 PR, the blocks of sensors, a controller and 2 sockets for connection of power, communication lines and transit. RS485 galvanic isolation protects from cross-talk in the connecting lines. Interface RS485 (speed – 38400 baud, length ≤1200m) allows to realize the distributed MS and the integration with automation systems [1, 4, 9].

The МИД-10 provides a measurement cycle ≤100 ms data transfer time ≤30 ms and a tolerance of ≤0.15%. In the МИД-10-1 probe module is a separate with PT type ТДМ-А (Testmodule absolute pressure) [10] and the amplifier of a signal normalizer that allows you to modify the device by installing different PT and calibration via RS485. The measurement and transmission of data ≤30ms. Allowed Daisy-chaining up to 32 devices, which increases the number of channels 320.

As MCPG apply pneumatic modules (fig. 3, c), which can be 16 measured with the number of channels 256 and more. The pneumatic module has 16 differential piezoelectric PT (different ranges, individual conversion functions) with built-in amplifiers, a voltage regulator and electronic switch. PT calibration is performed for a short time: PT group by range; at the same time is supplied a reference pressure; for each PT is determined by the transformation function

(polynomial) and evaluated the accuracy. The measurement time is calculated and experimentally verified for the PR depending on their lengths and diameters and diameters of the laterals.

Note that developer pressure *Freescale* provides detailed information [11].

Information - measuring system (IMS)

The unified structure of the IMS multi-channel pressure measurement with the use of EMPS and MS shown in fig. 4 [1, 9], where: C – computer; Cn - computer network; SC – sensors clock, CM – the control module, V_∞ – the flow rate, α - the angle of attack MA, ω – the speed of the rotor EMPS; P_c, P_u, P_s, P_e, P_i, P_0 – static, dynamic, reference, reference, pressure in the *i*-th drainage hole and pressure in accordance forkner; u_i – the output signal PT.
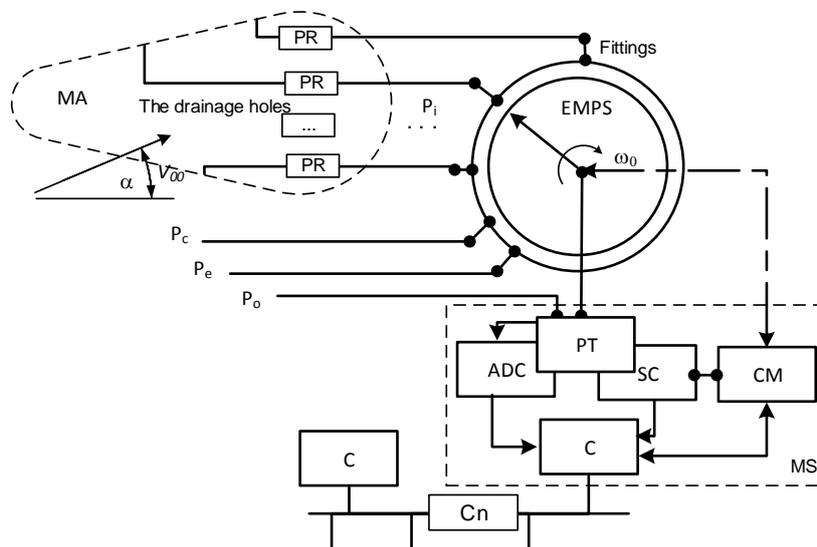

Fig. 4. The unified scheme of information - measuring system

The structure of IMS is universal, which can be implemented on different hardware and software platforms (*VME*, *PC/104*, *MicroPC*, etc.) [1, 8].

IMS provides the following algorithm [1, 8].

Step 1. Checking MS and the input of initial data.

Step 2. The problem of adaptive control ER (determination of control parameters) [5].

Step 3. Control ER in accordance with the conditions of the experiment in the experiment plan. If experiment plan is made, then go to step 7.

Step 4. Setting set in the experiment plan corners α, β and check benchmarks MS channels.

Step 5. The definition of control parameters and EMPS it to run at the required speed of flow in the working part of the WT.

Step 6. The collection of experimental data, rapid processing and analysis of the IMS. If correct, record them in the database and jump to step 2.

Step 7. Processing: determination of total and distributed aerodynamic characteristics of MA; analysis and documentation of ED, etc.

Step 8. End: exit the program ER.

Measuring system

The general scheme of MS serial type presented in fig. 5. The pressure P_i is fed PR to PT, the outputs of which through the measuring channel of the MS is connected to the input of the ADC, and then fed to registers of the computer C to where its registration, processing and analysis [1, 8].
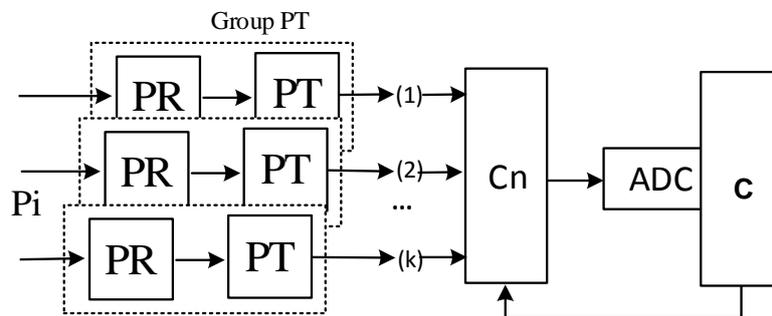
Fig. 5. Diagram of the measuring system series type

The algorithm of the measuring system for one experience like this.

Step 1. All of the conditions of the experience ER.

Step 2. The pressure from the drainage holes on PR is applied to the fittings EMPS.

Step 3. EMPS sequentially connects PR with PT, where the pressure P_i will turn is into an electrical signal u_i.

Step 4. Electrical signals from PT are served on the ADC is that the signal from ДС S_i is measured.

Step 5. On a signal S_i from the SC converts the analog signal u_i into digital and its registration.

Step 6. The end.

In the performance of ER under the scheme "point to point" is advisable to use the MS in parallel operation (fig. 6).
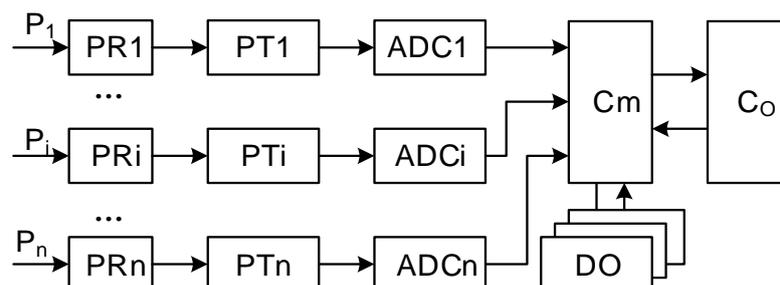
Fig. 6. The scheme of the measuring system of the parallel type

The algorithm works like this:

Step 1. Pressure PR (PR1, ..., PRn) with drainage holes arrives at the corresponding PT (PT1 ... PTn).

Step 2. The electrical signal PT through the respective transducers ADC1 ... ADCn forwarded to the computer Cm.

Step 3. Obtained by channel codes at the same time served on the registers of the computer to Cm, where in real time it is processed.

Step 4. Treatment results (main parameters, results of intermediate calculations) specified in the form are displayed on output (DO).

Step 5. Experimental data is transferred for further processing in the computer Co.

Along with treatment Cm provides simultaneous and independent control of each channel in accordance with the measurement algorithm.

EMPS interaction with the MS is performed according to this algorithm.

Step 1. Installation EMPS to its original position and the collection of "zero" indicators PT.

Step 2. On arrival the command "Start" is issued EMPS startup code (start of rotation of the rotor).

Step 3. On the arrival of the synchronization signal S_i from the control module (CM) registers the data of the experiment from the respective PT.

Step 4. With the arrival of the command "end cycle" sends the command "stop EMPS".

Step 5. End: exit management EMPS.

In a distributed MS, the exchange of information between the processor module and PT is implemented using RS-485/ CANbus, which are built into each controller (fig. 7) [8]. Such a distributed MS is efficient because it significantly reduces hardware costs associated with the presence of uniform blocks.
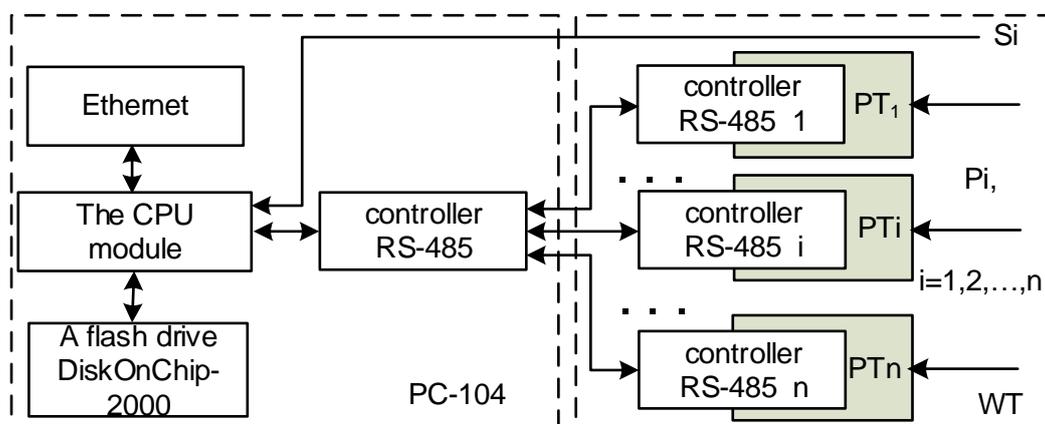

Fig. 7. Scheme of a distributed measurement system.

Primary processing

Calculate the absolute and relative value of pressure, sorting pressure on the incisions and documentation of results ER.

Let be the u_{ij} array of ED ($n \times m$), which is equivalent to the corresponding value of pressure ($u_{1j} \sim P_{sj}$, $u_{2j} \sim P_{ej}$ and $u_{3j} \sim P_{ej}$ for $j = 1, 2, ..., m-1$, $u_{im} \sim q_i$ for $i = 1, 2, ..., n$, $u_{ij} \sim P_{ij}$ for $i = 4, 5, ..., n$, $j = 1, 2, ..., m-1$), where i is the number of the cycle EMPS ($i = 1, 2, ..., n$), j – the number of the fitting EMPS ($j = 1, 2, ..., m$). Then the pressure value is determined via the functions Z (implemented as procedures).

Define array of valid values static, the reference pressure and the pressure in any drainage hole model of the aircraft is:

$$P_{sj} = Z_s \left[\sum_{k=0}^{\xi_s} a_k^s u_{1j}^k \right]; \qquad P_{ej} = Z_e \left[\sum_{k=0}^{\xi_e} a_k^e (\frac{u_{2j} + u_{3j}}{2})^k \right];$$

$$P_{ej} = \begin{cases} Z_d \left[\sum_{k=0}^{\xi_d} a_k^d (u_{ij} - u_{1j})^k \right] \text{ - nonlinear;} \\ \dfrac{P_e}{P_{ej}} (u_{ij} - u_{1j}) \text{ - linear conversion functions,} \end{cases} \qquad (2)$$

where $a_k^{<w>}$, $w = \{s, e, d, q\}$ – is the coefficients of the conversion functions PT; $\{\xi_k\}_{k \in w}$ – the number of coefficients.

The dynamic pressure in the working part of the WT is constantly pulsing [5, 9] that need to be considered when processing the data of the experiment. Therefore its value and the relative pressure value is determined so:

$$q_i = Z_q \left[\sum_{k=0}^{\xi_q} a_k^q (u_{im} - u_{1m})^k \right], \qquad \bar{P}_{ij} = Z_0 \left[\frac{P_{ij}}{\mu q_i} \right],$$

where μ the coefficients field of the WT.

If $R_{\eta\lambda}$ matrix matching the placement of the drainage holes on the AM and their connection to EMPS, it $\bar{P}_{\eta\lambda} = Z_g \left[R_{\eta\lambda} \right]$, where $\eta = 1, 2, ...$ – the numbers of the sections; λ – the procedure for placing drain holes ($\eta \times \lambda \leq m \times n$).

If r the number of repetitions, the average value of relative pressure and its standard error are defined so:

$$\hat{\bar{P}}_{\eta\lambda} = \frac{1}{r} \sum_{k=1}^{r} \bar{P}_{\eta\lambda}^{<k>}; \qquad \sigma_{\eta\lambda} = \sqrt{\frac{1}{r-1} \sum_{k=1}^{r} \left(\hat{\bar{P}}_{\eta\lambda}^{<k>} - \bar{P}_{\eta\lambda}^{<k>} \right)^2}. \qquad (3)$$

By measuring the reference pressure was built histogram and tested the hypothesis about normal distribution law of the ED using the Pearson criterion (χ^2). In our case, $\chi = 7.13$ with an acceptable reliability $\gamma = 0.95$.

To assess the value of relative pressure using a confidence interval with reliability γ in use Student's distribution, i.e.

$$\left(\widehat{\overline{P}}_{\eta\lambda} - t_\gamma \frac{\sigma_{\eta\lambda}}{\sqrt{r}}, \ \widehat{\overline{P}}_{\eta\lambda} + t_\gamma \frac{\sigma_{\eta\lambda}}{\sqrt{r}} \right), \text{ where } t_\gamma(\gamma, r) - \text{ known table value.}$$

In the case of repeated experiments, which performed normally in the same conditions ED are checked for statistical reproducibility on the criterion of Cochrane:

$$G = \frac{\sigma_{max}^2}{\sum\limits_{i=1}^{N} \sigma_i^2},$$

where $\sigma_{max}^2 = \max\{\sigma_i\}_{i=1}^{N}$; σ_i^2 – the variance value for i the experience (3); N ‒ the total number of experiments.

If $G \leq G_t$ for $\nu_1 = m - 1$, $\nu_2 = N$, $\alpha = 0,05$, it ED homogeneous and their error is estimated as: $\delta^2 = \dfrac{1}{N} \sum\limits_{i=1}^{N} \sigma_i^2$.

In fig. 8 shows the RMS error of determining the values of pressure, depending on the location of the drain holes on the MA and angle α.

The Reynolds number in terms of the ER is defined as:

$$\text{Re} = \sqrt{\frac{2gl}{3\nu}}, \text{ where } \nu = \frac{P}{\rho_{15}}(1{,}745 + 0{,}005t)10^{-6}; \ P = \frac{0{,}0474P_a}{273{,}15 + t}; \ t \ - \text{ the temper-}$$

ature in the WT; ρ_{15} – the density of air at $t = 15^\circ C$; P_a ‒ barometric pressure; l – the characteristic size of the MA.

The reliability of ED is ensured by the algorithm of operative control of work of IMS [1, 9]. Registration u_{ij} is accomplished when the correct operation of the technical equipment of the system. ED is stored $\overline{P}$ if the control points are correct. Otherwise, the experience is repeated. In fig. 9 shows a plot of distribution of relative pressures in the two sections of the MA.
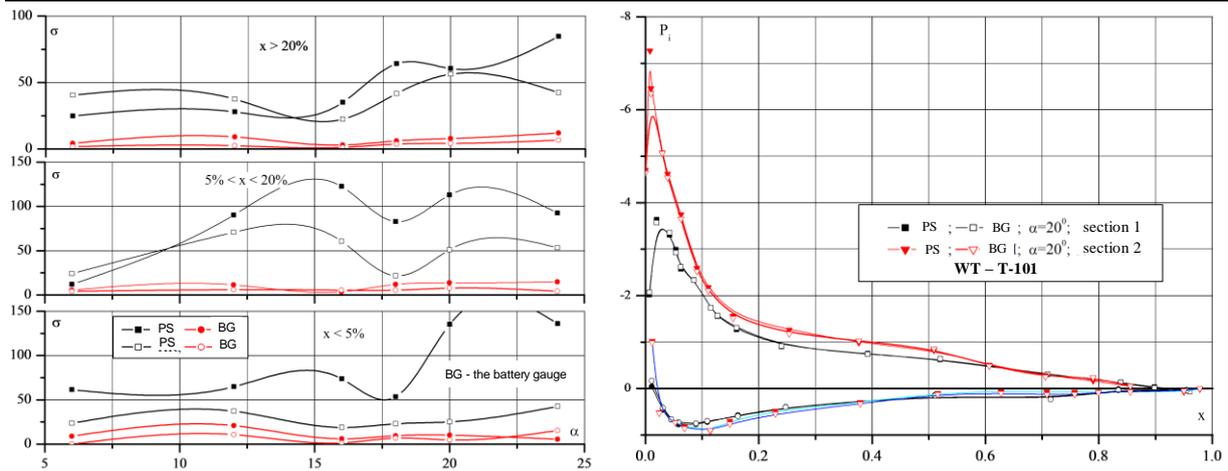
Fig. 8. The dependence of errors from the placement of the drainage holes

Fig. 9. Plot of pressure distribution chordwise wing aircraft model

The definition of conversion functions

Increases the accuracy of determining the pressure (2) due to the representation of transformation function of PT in the form of a polynomial (fig. 10):

$$\hat{Y} = \sum_{i=0}^{m} a_i x^i , \qquad (4)$$

where Y, X – the vector measured value and setpoint of the reference pressure;

$\hat{Y}$ – the vector of approximate values of pressure; m – the order of the polynomial.
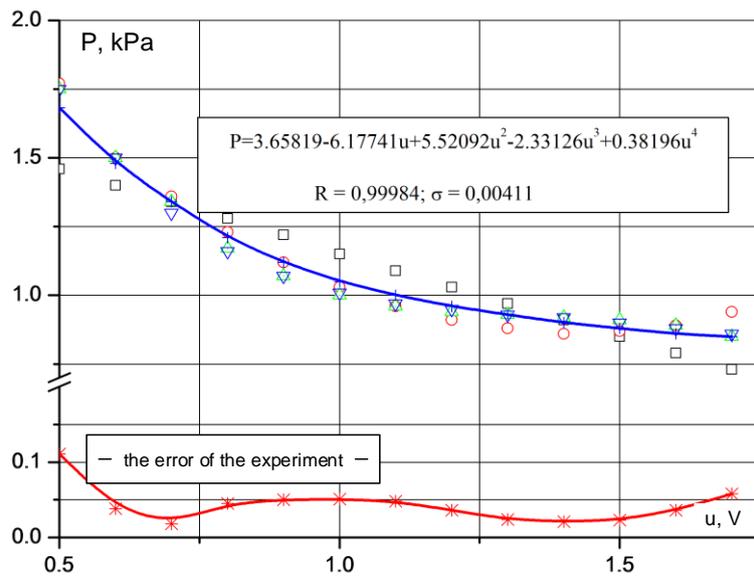
Fig. 10. The transformation function for the pressure sensor

Equation (4) is determined from the condition of the minimum sum of squared deviations between Y and $\hat{Y}$, i.e.: $\min Q_p = \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2$, where n - the number of experiments.

If x_i, y_i there i is one element in the vectors X and Y, then the orders of the independent variable can be defined as $x_{ij} = x_i^j$, where $i = 1,...,n$; $j = 1,...,m$. Computing process for (4) ends when $Q_p \le Q_{p+1}$, where $p \le m-1$. When implementing this method uses the following ratios.

The average value and the sum of the mutual works calculated so:

$$\bar{x}_j = \frac{1}{n}\sum_{i=1}^{n} x_{ij}; \quad D_{jk} = \sum_{i=1}^{n}(x_{ij} - \bar{x}_j)(x_{jk} - \bar{x}_k) - \frac{1}{n}\sum_{i=1}^{n}(x_{ij} - \bar{x}_j)\sum_{i=1}^{n}(x_{ik} - \bar{x}_k),$$

where $j = 1,...,p$; $k = 1,...,p$.

The correlation coefficients and standard deviations:

$$r_{ij} = \frac{D_{ij}}{\sqrt{D_{ii}D_{jj}}}; \quad S_j = \frac{1}{\sqrt{n-1}}\sqrt{D_{jj}}.$$

Determination of beta-weights, the estimates of the regression coefficients, the free term and the coefficient of multiple correlation is performed in the following ratios:

$$\beta_j = \sum_{i=1}^{k} r_{ij}r_{jj}^{-1}; \quad \alpha_j = \beta_j \frac{S_y}{S_j}; \quad \alpha_0 = \bar{y} - \sum_{j=1}^{m}\alpha_j\bar{x}_j, \quad R = \sqrt{\sum_{i=1}^{n}\beta_i r_{ij}}.$$

The sum of squares that relates to regression, sum of squares of deviations from regression and the values of Fisher criterion are defined so:

$$S_R = R^2 D_{yy}; \quad S_S = D_{yy} - S_R; \quad F = \frac{n-k-1}{k}(S_r / S_s).$$

Variance, standard error estimate, the standard errors of the regression coefficients and the coefficients of the Student t_j are defined so:

$$S_y^{\,2} = \frac{S_s}{n-k-1}; \quad S_y = \sqrt{S_y^{\,2}}; \quad S_{aj} = \sqrt{\frac{r_{ij}^{-1}}{D_{ij}}S_y^{\,2}}; \quad t_j = \frac{a_j}{S_{aj}}.$$

The significance of any coefficient in (4) is estimated using t - statistics of the Student. The condition $t_i > t_{0.05,n-m-2}$ shows the significance of the regression coefficient a_i. The removal is not significant coefficients of (4) requires recalculation of the model.

Testing the significance of (4) is done in F - statistics, in which (4) is an important if $F > F_{0.05,n-2,1}$. Otherwise, you must change the order (4), to check ED or to perform a linear transformation of the independent variable.

If the conversion function PR is affected by other factors (temperature humidity, etc), it is necessary to apply the optimal scheme of setting values of

influence factors in the sense of minimum number of experiments, i.e., D the optimal plans of the experiment (tab. 1.). The conduct of randomized experiments, a small number of experiments compared to the number of coefficients in (4) [12].

Table **1.**

Experience	1														
Factor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**0**	**1**	**2**	**3**	**4**	**5**
x_1	−	+	−	+	−	+	−	+	−	+	0	0	0	0	0
x_2	−	−	+	+	−	−	+	+	−	−	−	+	0	0	0
x_3	−	−	−	−	+	+	+	+	0	0	0	0	−	+	0

The method is implemented in the form of this procedure [5, 12].

Step 1. Generating of the experiment plan and the formation of tables of reference values of influence factors.

Step 2. Choice i-th row of experiment plan and real values of factors of influence on PT.

Step 3. Obtaining of the experimental data and check them for errors. If the experiment plan is not fulfilled, then go to step 2.

Step 4. The formation of the i-th row of the matrix X (table reference factors).

Step 5. The inspection of uniformity ED by the criterion of Cochran. If ED is uniform, then go to step 7.

Step 6. The row selection plan of the experiment with "gross" errors and the transition to step 2 (repeat experience).

Step 7. The choice of the optimal (4) and the definition of its coefficients.

Step 8. Testing the significance of coefficients (4), its relevance and adequacy. If criteria are not met, then go to step 7.

Step 9. Document conversion functions PT.

Step 10. The end.

Total characteristics

The coefficients of longitudinal c_{N_p} and c_{R_p} normal components of aerodynamic force, the coefficient of longitudinal moment m_{Z_p}, the relative position of the center of pressure x_d:

$$c_{Np} = \oint \overline{P}(\overline{x})d\overline{x}; \qquad c_{R_p} = \oint \overline{P}(\overline{y})d\overline{y};$$

$$m_{Zp} = \frac{1}{2}\oint \overline{P}(\overline{x})d\overline{x} - \tfrac{1}{2}\oint \overline{P}(\overline{y})d\overline{y}; \qquad \overline{x}_d = -\frac{m_{Z_p}}{c_{N_p}}. \tag{5}$$

Further, in the related coordinate system defined by the corresponding coefficients in the current axes:

$$c_{Y_p} = c_{N_p} \cos\alpha - c_{R_p} \sin\alpha; \; c_{X_p} = c_{N_p} \sin\alpha - c_{R_p} \cos\alpha.$$

Normal N and tangential T components of aerodynamic force are determined so: $N = c_n S q_\infty$; $T = c_\tau S q_\infty$, where S - the characteristic size MA; q_∞ - the dynamic pressure in the working part of the WT. In fig. 11 shows an example of the overall characteristics of the wing MA.

Problem (5) is to compute the integral of a table function with a minimum error. For this purpose methods of numerical integration [13], where $f(x)$ replaced interpolating /approximating function $P(x)$, i.e.

$$\int_a^b f(x)dx = \int_a^b P_{n-1}(x)dx + \int_a^b R_{n-1}(x)dx.$$

Have the formula of Newton – Cotes, if $[a,b]$ divided into n equal parts, that is $x_i = a + h(i-1)$, $h = (b-a)/n$, $i = 0,1,...,n$:
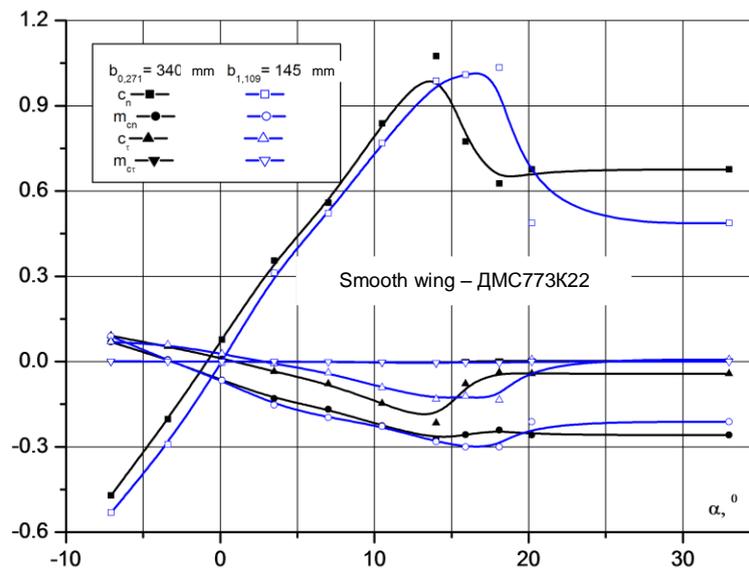

Fig. 11. The total aerodynamic characteristics of aircraft model

$$\int_a^b f(x)dx \approx (b-a)\sum_{k=1}^n H_k y_k, \tag{6}$$

where: $y_k = f(a + kh)$, $\quad t = \dfrac{x - x_0}{h}$ $\quad H_k = \dfrac{(-1)^{n-1}}{nk!(n-k)!}\int_0^n \frac{t(t-1)...(t-n)}{t-k} dt$,

$H_k = const$, $R = -\dfrac{(n!)^4}{[(2n)!]^2(2n-1)}(b-a)^{2n+1} f^{(2n)}(\zeta)$, $\zeta \in (a,b)$.

If $n = 1$ you have a trapezoid

$$\int_a^b f(x)dx \approx \frac{b-a}{2n}(y_0 + 2y_1 + 2y_2 + \cdots + 2y_{n-1} + y_n)$$

where $y_k = f\left(a + \frac{b-a}{n}k\right)$, $k = 0,1,...,n$, $R = -\frac{(b-a)^3}{12n^2}f''(\xi)$, $\xi \in (a,b)$.

In $n = 2$ (6) and $[a,b]$ divided into $2m$ equal parts, we have the formula of Simpson:

$$\int_a^b f(x)dx \approx \frac{b-a}{2m}\left(y_0 + 4y_1 + 2y_2 + \cdots + 2y_{2m-2} + 4y_{2m-1} + y_{2m}\right),$$

$$R = -\frac{h^5}{90}mf^{(iV)}(\xi), \quad \xi \in (a,b).$$

As in (6) we can construct a set of approximate expressions like $\int_{-1}^{1} f(x)dx \approx \sum_{i=1}^{n} B_i f(t_i)$, where B_i - permanent, t_i - segments with $[-1,+1]$. If B_i so ask to make the expression exact for any polynomial of order $\le n$, $f(x) \equiv 1$ we get a formula for Chebyshev:

$$\int_a^b f(x)dx \approx \frac{b-a}{2}\sum_{i=1}^{n} f(x_i); \quad x_i = \frac{b+a}{2} + \frac{b-a}{2}t_i; \quad \sum_{i=1}^{n} t_i^k = \frac{k(k-(-1)^{k-1})}{2(k+1)};$$

where $k = 1,2,...,n$.

If x_i and B_i so ask to make the expression exact for polynomials $Q(x)$ of order $\le Q(x)$ $2n-1$ ($\omega_n(n) = (x-x_1)(x-x_2)...(x-x_n)$ orthogonal to all $Q(x)$ order $\le n$, and are $[-1,+1]$ the Legendre polynomials $P_n(t) = \frac{1}{2^n n!}\frac{d^n(t^2-1)^n}{dt^n}$, roots of $t_1,t_2,..., t_n$ which are real and symmetric), we obtain the formula of Gauss:

$$\int_a^b f(x)dx = \frac{b-a}{2}\sum_{i=1}^{n} A_i f(x_i), \qquad \text{де } x_i = \frac{b+a}{2} + \frac{b-a}{2}t_i.$$

Formula Georgi:

$$\frac{1}{h}\int_{x_0}^{x_0+nh} f(x)dx = \frac{1}{2}y_0 + y_1 + \cdots + y_{n-1} + \frac{1}{2}y_n + A_2(\Delta y_n - \Delta y_0) - A_3(\Delta^2 y_{n-1} - \Delta^2 y_1) + ...,$$

where $A_k = \int_0^1 \frac{t(t-1)...(t-k+1)}{k!}dt$, when $x_i = x_0 + (i-1)h$ set $y_i = f(x_i)$ and $\Delta^k y_i$, $i = 0,1,...n$; $k = 1,2,...,n$, A_k is determined from the following recurrence

$$A_0\frac{1}{k} - A_1\frac{1}{k-1} + A_2\frac{1}{k-2} - ... + A_{k-1}(-1)^{k-1} = 0, \ A_0 = 1.$$

Methods were tested on functions $f(x) = \frac{1}{1+x^2}$ on $[0,1]$

(the exact value – $\pi/4 = 0.7853981634$;
error of the Newton – Cotes – $6.28664*10^{-6}/2.40812*10^{-8}$,
Georgi - $4.52093*10^{-5}$, Simpson – $4.01015*10^{-12}$, Romberg - $2.35630*10^{-12}$).
Suitable for the considered problems of using the method of Romberg.

Conclusions

Considered multi-measure pressure in the WT, which can stosowania both autonomously and as part of automated systems. The problems of experimental studies aimed at simultaneous measurement of air pressure in the apertures distributed on the MA and jet engines. It is shown that when designing an IMS it is necessary to consider the specifics means of multi-channel pressure measurements. Proposed the most efficient design of distributed IMS by using the standards: MicroPC, PC-104, etc.

The materials can be used for laboratory and research work in universities and research in industry.

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