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CALIBRATION OF PRESSURE MEASUREMENT CHANNELS IN WIND TUNNELS

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Abstract—*The article deals with the calculation of errors due to measurement using experiments with unmanned aerial vehicles in a wind tunnel. The hardware and methods used for calibrating pressure channels are described. Features of the measurement in a wind tunnel are researched. The basic devices for measuring pressure characteristics are listed. The features of measuring pressure in the wind tunnel are discussed. The functional chart for calibration of the pressure measuring channel is shown. The conversion unit applied in the measuring process was proposed. The approach for estimating relative errors is represented. The assessment of errors specific to measuring high-velocity head has been implemented. Both absolute and relative errors inherent in determining velocity head were calculated. Measurement errors of airflow speed have been analysed. It is revealed that the airflow speed can be calculated based on indirect nonlinear measurement. The obtained results could be used in testing unmanned aerial vehicles of different types. They can also be applied to measuring the pressure in various experimental equipment.*

Keywords—Wind tunnel; experimental test; calibrating technique; pressure measurement; calculating errors.

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) are now widely used across a range of applications. The relevant phase to advance UAV development is by enhancing their aerodynamic performance [1], [2]. A key stage in this process involves investigating the aerodynamic characteristics of UAVs through wind tunnel testing [3]–[5].

Such testing includes measuring parameters like dynamic pressure (head velocity), airflow speed, and aerodynamic force and moment coefficients [6]. Accurate measurement of these parameters requires reliable error models to evaluate the quality of the data obtained. In particular, improving the calibration methods used in wind tunnel experiments is essential. Of special importance is the calibration of pressure measurement channels, which calls for refined instrumentation and techniques to ensure precise pressure readings.

The primary objective of this article is to analyze measurement errors that occur when determining the aerodynamic characteristics of UAVs during wind tunnel experiments.

The structure of the paper is as follows: Section 2 focuses on the calibration process for pressure measurement channels. Section 3 examines errors in head velocity measurements, including both absolute and relative errors. Section 4 presents an assessment of systematic errors in airflow speed measurements. Finally, Section 5 summarizes the key findings.

II. CALIBRATION OF MEASUREMENT PRESSURE CHANNELS

Calibration of the pressure measuring line is conducted at the beginning of the study to minimize conversion errors within the measurement system. The calibration results include factors of an approximation polynomial that characterizes the conversion function of measuring line, as well as an assessment of possible measurement errors. These polynomial coefficients are then used throughout the experimental process [7]–[9].

The pressure instrumental channel consists of an MPXV5004G pressure gauge (Freescale Semiconductor) and an analog-to-digital converter (ADC) integrated into the IBS interface board. The main sources of pressure instrumental error are.

- Constant offset in the sensor output. The MPXV5004G sensor exhibits a constant component typically ranging from 1 V to 1.25 V. This introduces a systematic additive error that remains stable during experiments under temperature fluctuations do not exceed ±5 °C
- Sensitivity error and nonlinearity: The MPXV5004G sensor has a systematic multiplicative

error due to sensitivity deviations and nonlinearity in its transfer function. This error does not exceed 2.5% of the maximum output signal deviation.

- Output signal noise. The sensor output includes a random noise component, which has been experimentally determined not to exceed 5 mV.
- ADC zero shift represents an additive systematic constituent that arises in ADC gauging. The value of the shift is no more than the lower digit of the given gauging range.
- ADC nonlinearity. The nonlinearity in the ADC's conversion characteristic is a systematic error that does not exceed one LSB.
- Quantization noise is a random component with the root mean square value of $\sigma = Q/\sqrt{12}$. The parameter Q is defined by the LSB of the input code.

The PCI-1747U card is applied for voltage signals from –5 to 5 V. The characteristic of the LSB of the initial code Q is characterized as $Q = 10/2^{16} = 152\ \mu\text{V}$, and $\sigma = 14\ \mu\text{V}$. Meanwhile, the constituent of pressure gauging error for analog-to-digital conversion will be $\sigma_p = \sigma / s = 5 \cdot 10^{-3}\,\text{mm H}_2\text{O}$. This value is noticeably less than the random transformation errors of MPXV5004G pressure meters (value of output noise up to 5 mV). Errors of analog-to-digital conversion can be ignored, and the basic causes of pressure gauging errors are the transformation errors of pressure meters. To decrease the influence of systematic error factors on the pressure determination process, gauging of the measurement line as a whole is realized [10]–[12]. The diagram illustrating the gauging of the pressure measurement line is shown in Fig. 1.

The reference unit represents a micro manometer with a maximum measuring error of absolute pressure determination of 0.02 mm of water column (0.2 Pa).

Gauging is carried out using the reference value of pressure. It is determined concerning to atmospheric pressure, enters the micro manometer and simultaneously to the pressure meter at the direct input of the meter (input $P+$) by a single pneumatic line.

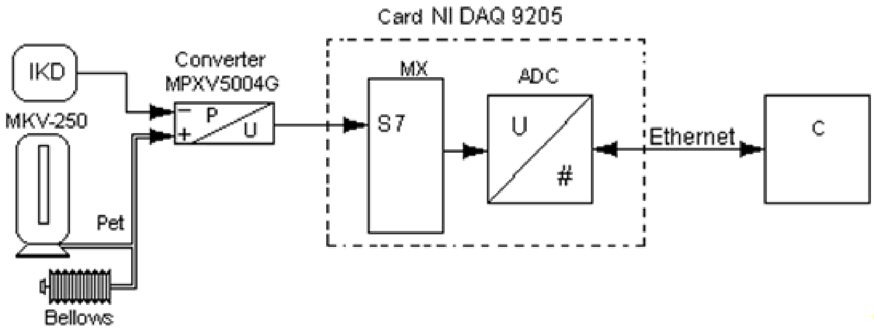

Fig. 1. Volumetric vortex generators of three types for the NACA0012 aerodynamic airfoil model

During gauging, atmospheric pressure enters the negative input (P–) of the pressure meter, while the reference pressure – generated using a bellows – is applied to the positive input and set higher than atmospheric pressure. This configuration is intentional: during actual experiments, the working air pressure at the inlet (also applied to the sensor's negative input) is expected to be lower than atmospheric pressure. As a result, the pressure difference across the sensor's diaphragm during calibration matches the direction of the pressure differential during real experimental conditions [13], [14].

Manometer readings are manually recorded and transferred to a computer. Simultaneously, the sensor's output signals – proportional to the pressure difference between its positive and negative inputs – are measured by the data acquisition system and logged electronically.

Calibration is carried out by gradually increasing and then decreasing the reference pressure in cycles, within the range of 0 to 120 mm H_2O (1.2 kPa). For each reference pressure value, output signal measurements are taken repeatedly (at least 5000 samples) and subjected to statistical processing. This averaging minimizes the impact of random errors due to sensor output noise and ADC quantization noise.

Experimental analysis of the noise characteristics shows that the output voltage levels of the pressure sensors follow a probability distribution close to the normal (Gaussian) law. Given that the maximum noise amplitude does not exceed 5 mV, the root mean square (RMS) noise value is approximately $\sigma \approx 1.6$ mV. Averaging 5000 readings reduces this value by over 70 times, resulting in a final RMS error of approximately $\sigma_{av} \approx 0.02\,\text{mV}$. This corresponds to a pressure of 0.002 mm H_2O. Such a small error is negligible compared to other sources, such as the temperature instability of the pressure meter, the conversion nonlinearity, and the hysteresis of the meter's characteristic. All these factors can introduce errors up to 2.5% of the maximum pressure (several mm H_2O). Additionally, the noise-related error is more than 10 times smaller than the error inherent in micromanometer pressure measurements. Therefore, the influence of random noise from the pressure sensors on the calibration accuracy can be safely ignored

As a consequence of the gauging, the conversion function of the measuring line is determined. It can be approximated by a polynomial that can be expressed by the expression [14]:

$$P_j = \sum_{i=0}^{n} a_i \cdot U_{sj}^i \tag{1}$$

here a_i are the polynomial's factors; U_{sj}^i are the voltages at the pressure meter output, and n is the the polynomial's degree.

The use of the measurement line conversion function (1) accounts for nearly all components of systematic error, including additive, multiplicative, and nonlinearity errors resulting from signal conversion in the measurement lines [13], [14].

When selecting the polynomial's order n for the transformation function, it is important to consider that additive and multiplicative errors are already compensated by a first-degree polynomial. Reducing the nonlinearity error, however, requires the use of higher-order polynomials.

Nonetheless, applying a correction based on such a polynomial outside the calibration range (for pressures exceeding 1.2 kPa) can significantly increase the conversion error. For this reason, a first-degree polynomial approximation (n = 1) was chosen.

The gauging procedure for the measurement lines consists of the following stages [13], [14]:

- manual or semi-automatic control of the gauging process, where the operator is prompted to set the required pressure level at the sensor input using a micro manometer;
- real-time monitoring of gauging using instantaneous voltage and pressure readings in each channel, displayed in both tabular and multi-channel graphical formats on the user interface;
- recording of reference pressure values at the sensor inputs;
- multiple measurements of reference pressures for each measuring line, followed by storage of the recorded data;
- preliminary gauging data statistical processing;
- polynomial approximation of pressure meters transient performances;
- assessment of approximating errors for measuring line: the root mean square of the pressure determination error is defined based on approximating conversion performances and reference values of measured pressure;
- recording and storage of the polynomial coefficients, which are used in subsequent modeling and experimental stages.

The collected calibration data are compiled into a calibration protocol, which includes the polynomial coefficients and associated accuracy metrics.

Experimental calibration results demonstrated a high level of accuracy. The root mean square error of the pressure measurement was found to be less than: $\sigma < 0.035$ mm H_2O (0.35 Pa) for the root mean square value of the approximating error. The maximum pressure measuring error does not exceed $\Delta = 0.067$ mm H_2O (0.7 Pa). Hence, the combined relative error of measured pressure is characterized by the parameter of $\gamma < 0.06\%$ within a range of 120 mm H_2O.

III. ASSESSMENT OF SPEED MEASURING ERRORS

The speed head in the wind tunnel with the special equipment can be calculated by the formula [14]

$$q = \zeta_{apr}\left[\left\langle P_f - P_r \right\rangle\right], \tag{2}$$

where $\Delta P_q = P_f - P_r$ is the pressure difference at the front point and the points of entering static pressures from the receiver of air pressure; ζ_{apr} is the pressure gauging characteristic of the air pressure receiver.
As far as the equipment calibration was designed specifically for the gauging line, the resulting pressure difference measurements can be treated as direct measurements. Therefore, the systematic error in calculating the pressure difference keeps within limits the gauging error.

During the experiments, the airflow velocity varied between 5 and 28 m/s. Correspondingly, the pressure sensor measured pressure differences in the range of 1.5 to 50 mm H_2O (15–500 Pa). The maximum absolute error in determining the pressure drop across the airflow receiver should be considered equal to the calibration error of the measurement channel $\theta_{\Delta P_q} = 0.7$ Pa .

The formula (2) can be written as [14]

$$q = \zeta_{apr} \Delta P_q . \tag{3}$$

Expressions (2), (3) show that speed head could be calculated based on indirect measurements. For calculating these measurements error, it is sufficient to prologarithmize and then differentiate the appropriate formula and to express it in terms of finite differences [14]:

$$\gamma_q = \frac{\theta_q}{q} = \frac{\theta_{\zeta apr}}{\zeta_{apr}} + \frac{\theta_{\Delta P_q}}{\Delta P_q}, \tag{4}$$

here γ_q is a relative error of the speed head; θ_q is the absolute error of the appropriate variable.

Blowing was implemented under the influence of the pressure in the preliminary chamber for $\Delta P_q = 15$ … 500 Pa. The pressure gauging factor was $\zeta_{apr} = 1.07...1.058$. Hence, the error of the pressure gauge factor ζ_{apr} used in the tests keeps within the level 0.002. The value of the total relative error γ_q (expression (4)) and absolute error θ_q are represented by the following calculations:

$$\begin{aligned} \gamma_q &= \frac{0.002}{1.07} + \frac{0.7}{15} \approx 0.049, \\ \theta_q &= \gamma_q q = 0.049 \cdot 15 = 0.73 \text{ Pa}, \end{aligned} \tag{5}$$

$$\begin{aligned} \gamma_q &= \frac{0.002}{1.058} + \frac{0.7}{500} \approx 0.0034, \\ \theta_q &= \gamma_q q = 0.0034 \cdot 500 = 17 \text{ Pa}. \end{aligned} \tag{6}$$

Finally, the relative total error of high-velocity pressure gauging will keep within limits $\gamma < 4.9\%$ at a velocity of 5 m/s, $\gamma < 1.6\%$ at a velocity of 9 m/s (ΔPq = 50 Pa), $\gamma < 0.57\%$ at a velocity of 18 m/s (ΔPq = 190 Pa), and will decrease to $\gamma < 0.34\%$ increasing in velocity up to 29 m/s.

IV. Assessment of Constant Errors of Airflow Velocity Determination

The airflow velocity calculated by measured values of the dynamic pressure is obtained using the expression [14]:

$$V = \sqrt{2q/\rho}\ ; \tag{7}$$

here q is the dynamic pressure; ρ is the density of air

The dynamic pressure is not measured in a wind tunnel.

After determination of a difference between the preliminary chamber and the atmosphere pressures, we can determine the dynamic pressure by the relationships [14]:

$$q = \xi_{apr} \cdot \langle P_{\text{atm}} - P_{prc} \rangle, \tag{8}$$

here ξ_{apr} is the gauging factor; P_{atm} is the pressure of the atmosphere; P_{prc} is a pressure within the chamber.

The wind tunnel represents an air pipe of the direct action with the dynamic pressure (8). The expansion of the air is explained by its passing through the preliminary chamber and the nozzle. The expansion is believed to be in accordance with the adiabatic law. Therefore, we can describe the ratio connecting air densities in the preliminary chamber and atmosphere by the expression

$$\frac{P_{prc}}{P_{atm}} = \frac{\rho_{prc}^{\kappa}}{\rho_{atm}^{\kappa}}, \tag{9}$$

here ρ_{prc}, ρ_{atm} are correspondingly the air densities in the preliminary chamber and in the atmosphere, $\kappa = c_v / c_p = 1.4$ is the air adiabatic coefficient in conditions close to normal. The static pressure, speed pressure, and hydraulic losses in the pipe section from the input unit to the operating wind tunnel together define the atmospheric pressure [14]

$$P_{prc} = P_{atm} - q/\mu_q. \tag{10}$$

After substituting the formula (10) into the expression (9), we can solve the obtained equation relative to ρ_{prc}:

$$\rho_{prc} = \rho_{atm}\left(1 - \frac{\langle P_{atm} - P_{prc}\rangle}{\langle P_{atm}\rangle}\right)^{1/1.4}. \tag{11}$$

After these calculations, the relationship (11) can be used together with formula (7) that gives us the following result:

$$V = \sqrt{\frac{2\mu_q < P_{prc} - P_{atm} >}{\rho_{atm}\left(1 - \frac{< P_{prc} - P_{atm} >}{\langle P_{atm}\rangle}\right)^{1/\kappa}}}. \tag{12}$$

As follows from the relationship (12), the airflow speed can be obtained based on nonlinear indirect measurements. In other words, the air density in the preliminary chamber can be determined by nonlinear indirect measurements. The calculation of the density of the air atmosphere must consider the air humidity, as it is shown in [15]. It is sufficiently difficult to analyse analytically the expressions given in [15]. Therefore, it is convenient to obtain the calculating coefficients based on measured air densities using the technique described in [16]:

$$\frac{\partial\rho}{\partial P_{atm}} = +0.0016\left(\text{kg/m}^3\right)\Big/\left(1\ \text{ mm Hg}\right),$$
$$\frac{\partial\rho}{\partial t_{atm}} = -0.045\left(\text{kg/m}^3\right)\Big/\left(1°\text{C}\right),$$
$$\frac{\partial\rho}{\partial \nu_{atm}} = -0.000075\left(\text{kg/m}^3\right)\Big/\left(1\%\right). \tag{13}$$

Relationships (13) are derived based on calculations of the air density in weather conditions that correspond to the procedure of processing data in the wind tunnel. The analysed errors are independent. Therefore, the general error of the measured air density can be obtained using the relationship shown below. The factor of humidity influence on the air density is insufficient for calculations. Therefore, we can apply the maximum error inherent in the psychrometer (7%) [14]:

$$\Theta_{\rho_{atm}} = \sqrt{\Delta_1^{\,2} + \Delta_2^2 + \Delta_3^2} = \sqrt{\left(0.0016\right)^2 + \left(0.0009\right)^2 + \left(0.000525\right)^2} = 0.0018\ \text{kg/m}^3. \tag{14}$$

here

$$\Delta_1 = \Theta_{P_{atm}}\frac{\partial\rho}{\partial P_{atm}},\quad \Delta_2 = \Theta_{t_{atm}}\frac{\partial\rho}{\partial t_{atm}},\quad \Delta_2 = \Theta_{t_{atm}}\frac{\partial\rho}{\partial t_{atm}}.$$

Introduce the notation

$$Q = 1 - \frac{\left\langle P_{atm} - P_{prc}\right\rangle}{P_{atm}}. \tag{15}$$

Now, we can rewrite the relationship (12), using the formula (15)

$$V = \sqrt{\frac{2\mu_q\left\langle P_{atm} - P_{prc}\right\rangle}{\rho_{atm} Q^{1/\kappa}}}. \tag{16}$$

The relationship (15) requires the analysis of its errors. Its accuracy is fully determined by the specific error q:

$$\Theta_Q = \Theta\left(\frac{\left\langle P_{atm} - P_{prc}\right\rangle}{\left\langle P_{atm}\right\rangle}\right). \tag{17}$$

If we take the logarithm and derivative of the relationship (17), we can write

$$\delta_Q = \frac{\Theta_Q}{Q} = \frac{\Theta_{\langle P_{\text{atm}} - P_{prc}\rangle}}{\left\langle P_{atm} - P_{prc}\right\rangle} + \frac{\Theta_{P_{\text{atm}}}}{\left\langle P_{atm}\right\rangle}. \tag{18}$$

The result determined by the relationship (18) is defined by the pressure drop in the preliminary chamber and the atmosphere. To simplify the approach, the changes of air pressure in the atmosphere are believed to be insignificant and equal to the standard P_{atm} of 760 mm. mercury or 101360 Pa. As $P_{atm-prc} = 0.7$ Pa, we can write

$$\frac{\Theta_Q}{Q} = \frac{\Theta_{\langle P_{atm} - P_{prc}\rangle}}{\left\langle P_{\text{atm}} - P_{prc}\right\rangle} + \frac{1}{\left\langle P_{atm}\right\rangle}. \tag{19}$$

To define the formula for the measuring error of the airflow speed in the wind tunnel, we prologarithmize and differentiate the relationship (16) considering the formula (19)

$$\frac{\Theta_V}{V} = \frac{1}{2}\left[\left(0.01 + 2\Delta\Theta_P\right) + \Delta\Theta_P + \frac{\Theta_{\rho_{atm}}}{\rho_{atm}} + \frac{1}{1.4}\left(\Delta\Theta_P + \frac{\Theta_{P_{atm}}}{\left\langle P_{atm}\right\rangle}\right)\right], \tag{20}$$

here $\Delta\Theta_P = \dfrac{\Theta_{\langle P_{\text{atm}} - P_{prc}\rangle}}{\left\langle P_{atm} - P_{prc}\right\rangle}$.

Three factors influence the relationship (20), including the difference in pressures in the preliminary chamber and atmospheric air. The basic error is defined by the changed pressure difference in the atmosphere and the preliminary chamber. Carrying out some transformations, we can write for standard weather conditions:

$$\left(\frac{\Theta_V}{V}\right)_{\text{bas}} = \delta_{V_{\text{bas}}} = 0.0062 + \frac{1.768}{\left\langle P_{\text{atm}} - P_{prc}\right\rangle}, \tag{21}$$

and the corrections on the deviation between atmospheric and standard conditions are defined by the relationships:

$$\Delta\delta_V\left(\rho\right) = \frac{0.0009}{\rho_{atm}} - 0.00073,$$

$$\Delta\delta_V\left(P_{atm}\right) = \frac{1}{P_{atm}} - 0.00094.$$

Results of the study are shown in Figs 2 – 4.

The results include graphs of the basic and additional systematic measuring errors based on relationships (14), (16), (19), (21) – (23).

The comparative analysis of graphical dependencies in Figs 2 – 4 shows that the basic speed measuring error is approximately in 50 times greater than the maximum values of the additional errors.

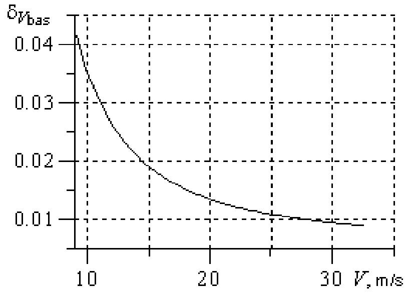

Fig. 1. Basic speed measurement error

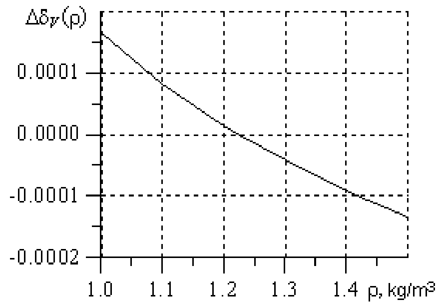

Fig. 2. Additional speed measurement error due to changes in density

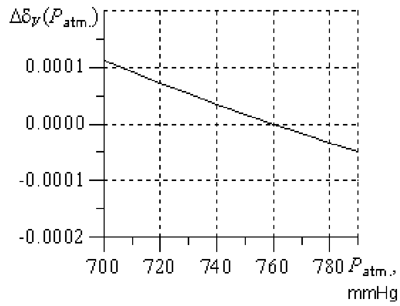

Fig. 4. Additional speed measurement error due to changes in barometric pressure

V. CONCLUSIONS

The hardware and methodology of the pressure measurement line are presented, along with expressions used to estimate the dynamics of the speed head.

Mathematical models have been developed to describe the systematic errors in airflow speed measurements. These models account for three main factors: the pressure difference between the atmosphere and the preliminary chamber, atmospheric air density, and atmospheric pressure.

Relevant graphical dependencies illustrating these relationships are provided. Additionally, an error analysis has been conducted for the determination of aerodynamic coefficients. Calibration errors of the scale measurement channels are also presented, and instrumental errors in the measurement of aerodynamic coefficients have been calculated.

REFERENCES

[1] E. P. Udartsev, et al., *Vortex Generator. Patent on useful model*. No. 67743 from 12.03.2012.

[2] E. P. Udartsev, et al., *The generator of longitudinal vortices*. Patent on useful model. No. 111701. 25.11.2016.

[3] J. S. Delinero, J. M. Di Leo, and M. E. Camocardi, "Vortex generators effect on low Reynolds number airfoils in turbulent flow," *International Journal of Aerodynamics*, 2 (1), 1: 14. 2020. https://doi.org/10.1504/IJAD.2012.046539

[4] P. S. Divekar and T. Ekbote, "Design of aerodynamic of an airplane wings," *IJSDR*, 4, 59–64, 2019. https://www.ijsdr.org/viewpaperforall.php?paper=IJSDR1910011

[5] A. G. Shcherbonos, *Aerodynamic characteristics of a wing with vortex generators in the conditions of non-stationary flow*, Dissertation of Ph.D. 2012, NAU, Kyiv. [in Ukrainian]

[6] S. I. Oleksienko, *Control of flow separation using longitudinal vortices generators*, Dissertation of Ph.D., 2018, NAU, Kyiv. [in Ukrainian]

[7] S. M. A. Aftab, N. A. Razak, A. S. Mohd Rafie, and K. A. Ahmad, "Mimicking the humpback whale: An aerodynamic perspective," *Progress in Aerospace Science*, 84, 48–69, 2016. https://doi.org/10.1016/j.paerosci.2016.03.002

[8] J. C. Lin, "Review of research on low-profile vortex generators to control boundary-layer separation," *Progress in Aerospace Sciences*, 38, 389–420, 2002. https://doi.org/10.1016/S0376-0421(02)00010-6.

[9] D. Custodio, C. W. Henoch, H. Johari, "Aerodynamic characteristics of finite span wings with leading-edge protuberances," *AIAA Journal*, 53(7), 1878–1893, 2015. https://doi.org/10.2514/1.J053568.

[10] A. K. Malipeddi, N. Mahmoudnejad, K. A. Hoffmann, "Numerical analysis of effects of leading-edge protuberances on aircraft wing performance," *Journal of Aircraft*, 49(5), 1336–1344, 2012. https://doi.org/10.2514/1.C031670.

[11] O. A. Sushchenko, and Y. N. Bezkorovainyi, "Improvement of UAV positioning by information of inertial sensors," in: *Proceedings of IEEE 5th International Conference on Methods and Systems of Navigation and Motion Control (MSNMC)*, Kyiv, Ukraine, 2018, pp. 151–155. https://doi.org/10.1109/MSNMC.2018.8576307.

[12] O. Zhdanov, V. Orlianskyi, and O. Sushchenko, "Research of aerodynamic characteristics of aviation profile model in conditions of artificial generation of large longitudinal vortices," *CEUR Workshop Proceedings*, 3732, 2024, pp. 149–160.

[13] O. Zhdanov, V. Orlianskyi, and O. Sushchenko, "Researching Influence of Vortex Generators on Aircraft Aerodynamic Characteristics," *Lecture Notes in Networks and Systems*, 992 LNNS, pp. 410–422, 2024. https://doi.org/10.1007/978-3-031-60196-5_30

[14] O. Zhdanov, O. Sushchenko, and V. Orlianskyi, "Analysis of Measuring Errors During Aerodynamic Research in Wind Tunnel," *Lecture Notes in Networks and Systems*, vol. 1418, pp. 3–19, 2025. Springer, Cham. https://doi.org/10.1007/978-3-031-91992-3_1

[15] D. Sundararajan, *Digital Signal Processing: An Introduction*. Springer, Cham, 2024. https://doi.org/10.1007/978-3-031-56740-7

[16] J. R. Tayor, *An Introduction to Error Analysis: the Study of Uncertainties in Physical Measurements*. Mill Valley, California, 2022.

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О. І. Жданов, О. А. Сущенко, В. В. Орлянський. Калібрування каналів вимірювання тиску в аеродинамічних трубах

У статті розглядається оцінка похибок вимірювальних систем під час експериментальних випробувань безпілотних літальних апаратів в аеродинамічній трубі. Описано прилади та методику, що використовуються для калібрування параметрів тиску. Охарактеризовано особливості вимірювання в аеродинамічній трубі. Перераховано основні джерела вимірювання тиску. Обговорено особливості вимірювання тиску в аеродинамічній трубі. Наведено структурну схему калібрувального каналу вимірювання тиску. Запропоновано функцію перетворення вимірювального каналу. Представлено підхід до оцінки відносних похибок. Здійснено оцінку похибок вимірювання високошвидкісного напору. Оцінено відносні та абсолютні похибки швидкісного напору. Оцінено похибки вимірювання швидкості повітряного потоку. Показано, що швидкість повітряного потоку є результатом непрямого нелінійного вимірювання. Отримані результати можуть бути корисними для випробувань безпілотних літальних апаратів різних типів. Вони також можуть бути застосовані для вимірювання тиску в різному експериментальному обладнанні.

Ключові слова: аеродинамічна труба; експериментальні дослідження; методика калібрування; вимірювання тиску; обчислення похибок.

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