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INFLUENCE NUMERICAL SCHEMES TO ESTIMATE ERROR OF AIR PRESSURE PROBE

M.M. Dubinina, M.Y. Sorokin
PJSC "Ulyanovsk instrument manufacturing design bureau"

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Abstract

This article discusses the selection of the numerical schemes and their impact on the results. Mathematical modeling of the external flow two layouts pitot probe using free software OpenFoam. For simulation of turbulent flow used most popular RANS model SST. In general, it is shown that various numerical methods lead to mathematical modeling errors from 0.5% to 4% of the measured velocity, other things being equal.

1 Introduction

The problem of pressure measurements on board is achieved by means of special devices – air pressure probes [1]. Increasing the accuracy of the measurement values of the total and static pressure in aircraft has been and remains an actual task. Testing and verification of the metrological characteristics of air pressure probes in a reasonable amount of time and require considerable expenses. There is a growing part of the mathematical modeling and laboratory tests may be replaced by mathematical modeling.

In this case the key issue remains the error mathematical modeling. Two layouts pitot probes, one of which is shown in Fig. 1, were investigated at Central Aerohydrodynamic Institute named after Prof. NE Zhukovsky (TsAGI). Determined angular characteristic of the receiver (the dependence of the perceived pressure from the angle of the incident flow) at a certain speed of air flow. Angular characteristic is one of the metrological characteristics of the pitot probe [2, 3].

Fig.1. General view of layout pitot probe

2 Modelling of layouts pitot probes

2.1 Model's description

Mathematical modeling performed in OpenFOAM [4] for the same reseach conditions (pressure, temperature), which were at the time of research. The free software OpenFOAM is very flexible in terms of settings and allows you to select any numerical schemes for the model parameters and to specify settings solvers.

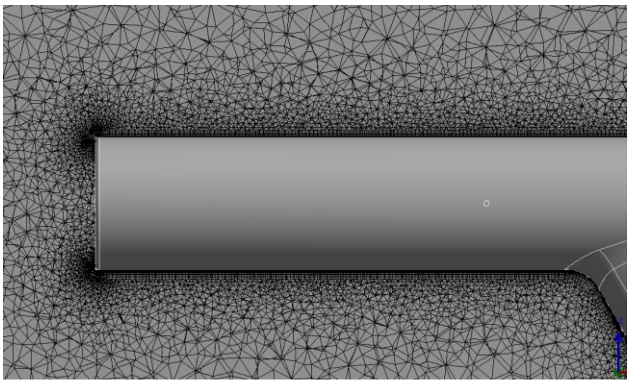

Fig. 2. Tetrahedral mesh with prismatic layers

To carry out the simulation tetrahedral mesh with prismatic layers was prepared in Ansys Meshing, which presents a general view in Fig. 2 and an enlarged view in Fig. 3. Grid's parameters correspond to the standard recommendations, the boundary layer is fully described prismatic elements, the parameter y + is less than 1.

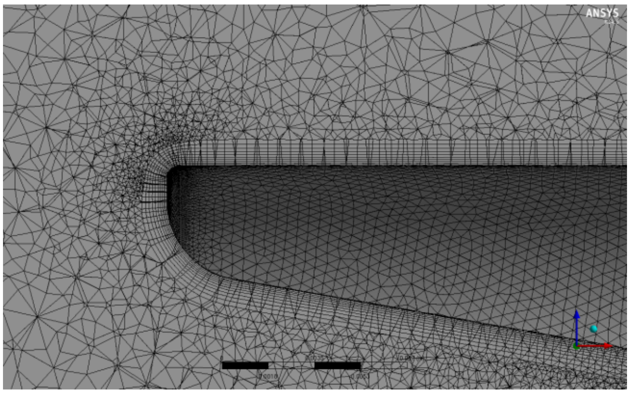

Fig. 3. Enlarge view of mesh

2.2 Description of mathematical modeling

In carrying out mathematical modeling used OpenFoam's solver simpleFoam, intended for calculation of steady-state incompressible turbulent flows. In the calculation does not take into account the roughness of the surface and mount the probe to the surface of the aircraft.

To model was chosen most popular RANS kOmegaSST model of turbulence, for all variants considered a grid with the same number of cells [5]. Simulation results were compared with data obtained during the experiment.

2.2 Boundary conditions and numerical schemes

When choosing a numerical solution schemes must take into account that they have a significant impact on the accuracy obtained by a solution. For comparison, it was considered 28 numerical schemes of the solution. Selected schemes that give extreme and average values of the error modeling. The parameters and settings, which are shown in Table 1.

As can be seen from Table. 1 on the "inlet" of the computational domain wondered corresponds to the free-stream velocity with low turbulence at its lateral boundaries of the flow was assumed undisturbed on the "outlet" of the computational domain was set boundary condition "free output with zero pressure" (which corresponds to the motion of a steady-state flow).

Table 1. Numerical schemes

Numerical schemes	grad schemes	var. 1 - Gauss linear; var. 2 - cellLimited leastSquares 1; var. 3 - cellLimited Gauss linear 1;	

	U	var. 1 - div(phi,U) Gauss linearUpwind grad(U);
		var. 2 - div(phi,U) Gauss limitedLinearV 1;
		var. 3 - div(phi,U) Gauss limitedLinearV 1;
		
		div((nuEff*dev(T(grad(U))))) Gauss linear;	

	k	var. 1 - Gauss upwind; var. 2 - Gauss limitedLinear 1; var. 3 - Gauss limitedLinear 1;	
Solver	p	GAMG tolerance relTol	 1,00E-12 0,01
	U, k, ω	SmoothSolver tolerance relTol	 1,00E-12 0,01
Boundary conditions	inlet	U	U=(X·cos(α), Y·sin(α), Z) α=(0°... 30°)
		k	$k = \frac{(b \cdot \lvert V \rvert)^2}{2}$
		ω	$\omega = \frac{k^{1/2}}{l}$
		p	∇ p = 0
	outlet, wall	ω	∇ ω = 0
		k	∇ k = 0
		p	0

Modeling of these numerical schemes was carried out on the technological platform of the "University Cluster" [6].

3 Results and discussion

Simulation result is a dynamic pressure *Pd* [Pa] in the tube of pitot probe at which airspeed *U* [m/s] was calculated by the formula

$$U = 760{,}92125 \cdot \sqrt{\left(1 + \frac{P_d}{101325{,}2}\right)^{\frac{1}{3{,}5}} - 1} \qquad (1)$$

The results of experiments and simulations for these two layouts pitot probes are shown in Table 2 and Table 3 respectively: α (alfa) — the angle of air flow; *Ue* — airspeed measured in the experiment, *U1*, *U2*, *U3* — airspeed of the simulation corresponding to the lowest, average and maximum error; $\delta U1$, $\delta U2$, $\delta U3$ — relative error of simulation, equal to the ratio of the absolute error (equal to the difference between the calculated and measured air velocities) to the current value of the measured airspeed corresponding to the lowest, average and maximum error.

The resulting error of the numerical schemes were evaluated over the entire range of angle of air flow and result numerical schemes is chosen by the integrated assessment of numerical schemes corresponding to the lowest, average and maximum error.

Table 2. First layout pitot probe

α, deg	*Ue*, m/s	*U1*, m/s	*δU1,%*	*U2*, m/s	*δU2,%*	*U3*, m/s	*δU3,%*
0	99.27	98.91	-0.36	99.76	0.49	101.49	2.23
5	99.23	99.32	0.10	100.84	1.62	102.45	3.25
10	99.06	99.02	-0.04	100.66	1.61	102.42	3.39
15	99.05	99.26	0.21	99.58	0.54	102.08	3.06
20	98.72	98.78	0.06	100.07	1.36	101.47	2.79
25	98.00	97.82	-0.19	98.54	0.55	100.22	2.26
30	95.80	96.24	0.46	96.87	1.12	98.85	3.19

Table 3. Second layout pitot probe

α, deg	*Ue*, m/s	*U1*, m/s	*δU1,%*	*U2*, m/s	*δU2,%*	*U3*, m/s	*δU3,%*
0	99.24	97.47	-1.78	97.86	-1.39	99.25	0.01
5	99.28	98.25	-1.03	98.93	-0.35	100.33	1.06
10	98.94	98.09	-0.86	98.67	-0.27	100.49	1.56
15	98.87	98.81	-0.06	97.75	-1.13	100.84	1.99
20	98.27	98.36	0.10	98.25	-0.02	100.27	2.03
25	97.03	98.07	1.07	98.33	1.34	99.86	2.91
30	95.07	96.73	1.74	97.12	2.16	98.17	3.26

Figure 4 and Figure 6 shows the dependence of velocity (experimental and three simulated velocities) on the angle of air flow 'α' respectively.

Figure 5 and Figure 7 shows the dependence of relative error on the angle of air flow 'α' respectively for the three selected numerical schemes for solving equations. Relative error modeling lies in the range from 0.5% to 4%. Thus, it is clear that the simulation pitot probe great contribution to the error made and received selected numerical schemes along with well-known modeling requirements of external flow of various bodies (mesh quality, y+, boundary conditions, turbulence properties).

The best choice of numerical schemes is for the rate of the second-order scheme (grad schemes - Gauss linear; div(phi,U) Gauss linearUpwind grad(U)), and for the turbulence parameters - the first order (Gauss upwind).

In this paper, were not considered the time spent for computation, but it should be noted that the numerical scheme with constraints (cellLimited, for example) increase computation time is almost twice.

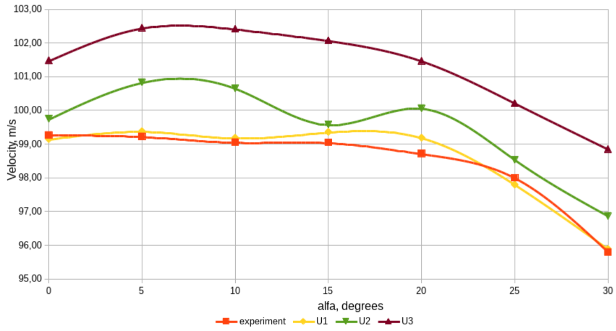

Fig. 4. First layout pitot probe - dependence of velocity on the angle of air flow 'α'

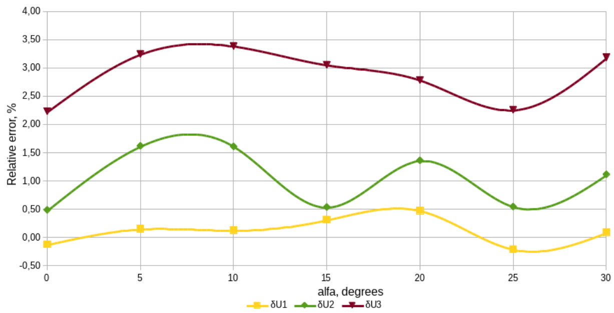

Fig. 5. First layout pitot probe - dependence of relative error on the angle of air flow 'α'

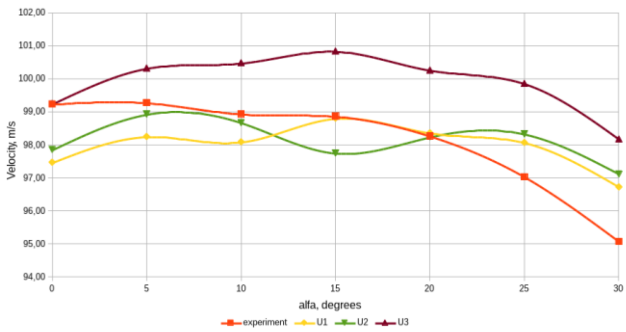

Fig. 6. Second layout pitot probe - dependence of velocity on the angle of air flow 'α'

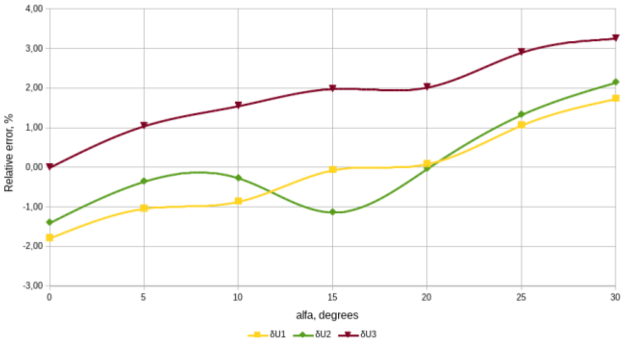

Fig. 7. Second layout pitot probe - dependence of relative error on the angle of air flow 'α'

3 Conclusion

Thus, in the work questions the choice of schemes numerical solutions of equations and the impact of these schemes on the accuracy of the mathematical modeling of pitot probes. The best choice of numerical schemes is for the rate of the second-order scheme and for the turbulence parameters - the first order. This option is provide relative error of less than 0.5-1% compared with the experimental data.

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Mikhail Sorokin
mailto: minich80@mail.ru

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