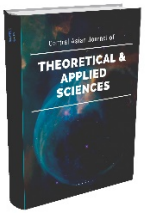

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Comparison of Numerical Results of Turbulence Models for Excessive Speed and Temperature in Waterflow

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Abstract: *A comparative analysis of two standard turbulence models SA and SST with experimental data of excess velocity and temperature in the satellite flow is carried out.*

KeyWords: *Reynolds averaged Navier-Stokes equations, numerical method, satellite flow.*

Introduction

The simplest jet flow is considered to be a free cocurrent jet flowing into a medium of the same density. The jet flowing out of the nozzle into the medium of the same density has two characteristic sections that differ in the flow structure: initial and main. [1-3] Sometimes a transitional area is also distinguished. In the initial section of the jet (which coincides with the outlet section of the nozzle), the flow velocity profile u0 is close to uniform. Within the initial section, the core of constant velocities is preserved, the width of which decreases linearly from the size of the inner diameter of the packing to zero.Outside the boundary of the section of constant velocities, the flow velocities decrease both towards the periphery of the flow and along the length of the jet.[4-6] Since the flow is turbulent, we will use the Reynolds-averaged Navier-Stokes system of equations (RANS) as a mathematical model. The equations of stationary transfer of momentum and temperature in a cylindrical coordinate system have the form:

$$\begin{cases} \dfrac{\partial u}{\partial x}+\dfrac{\partial rv}{r\partial r}=0, \\ \dfrac{\partial u}{\partial t}+u\dfrac{\partial u}{\partial x}+v\dfrac{\partial u}{\partial r}=\dfrac{\partial}{r\partial r}(r(v+v_t)\dfrac{\partial u}{\partial r}), \\ \dfrac{\partial T}{\partial t}+u\dfrac{\partial T}{\partial x}+v\dfrac{\partial T}{\partial r}=\dfrac{\partial}{r\partial r}\left(r\left(\dfrac{v}{\mathrm{Pr}}+\dfrac{v_t}{\mathrm{Pr}_T}\right)\dfrac{\partial T}{\partial r}\right); \end{cases} \quad . \qquad (1)$$

here νt- turbulent viscosity Pr, PrT - molecular and turbulent Prandtl numbers. The initial and boundary conditions for the system of equations (1) are set in a standard way [7-10]. In this work, to close the system of equation (1), we used the most modern and efficient turbulence models of Spalart – Allmars (SA) and Minter (SST-Shear stress transport-model of shear stresses). Spalart-Allmaras model - This model belongs to the class of one-parameter turbulence models:

$$\frac{\partial \rho \bar{\nu}}{\partial t} + \nabla(\rho \bar{\nu} u) = \rho(P_v - D_v) + \frac{1}{\sigma_v}\nabla\left[(\mu + \mu_t)\nabla\bar{\nu}\right] + \frac{C_{b2}}{\sigma_v}\rho(\nabla\bar{\nu})^2 - \frac{1}{\sigma_v \rho}(\mu + \rho\bar{\nu})\nabla\rho\nabla\bar{\nu}. \quad (2)$$

here $\bar{\nu}$- kinematic coefficient of vortex viscosity. The rest of the functions and constants were given in article [11,12].

turbulent eddy viscosity is calculated from:

$$\mu_t = \rho\bar{\nu} f_{v1}$$

Where

$$f_{v1} = \frac{x^3}{x^3 + c_{v1}^3}, \quad x = \frac{\bar{\nu}}{\nu}.$$

and ρ is the density, ν=μ/ρ is the molecular kinematic viscosity and

μ is the molecular dynamic viscosity. Additional definitions are given by the following equations:

$$\bar{S} = \Omega + \frac{\bar{\nu}}{k^2 d^2} f_{v2}.$$

where $\Omega = \sqrt{2W_{ij}\,2W_{ij}}$. - vorticity value, d is the distance from the field point to the nearest wall

$$f_w = g\left[\frac{1 + C_{w3}^6}{g^6 + C_{w3}^6}\right], \; g = r + C_{w2}(r^6 - r),$$

$$f_{v2} = 1 - \frac{x}{1 + x f_{v1}},$$

$$g = r + c_{w2}(r^6 - r), \; f_{t2} = c_{t3}\exp(-c_{t4}x^2),$$

$$r = \min\left[\frac{\bar{\nu}}{\bar{S}k^2 d^2}, 10\right],$$

$$W_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} - \frac{\partial u_j}{\partial x_i}\right)$$

The rest of the values are constants of the model and are presented in (tab. 1) [2].

Table 1. Konstants of the SAmodel

σ_v	k_r	C_{b1}	C_{b2}	C_{v1}	C_{w1}	C_{w2}	C_{w3}
2/3	0.41	0.1335	0.622	7.1	$C_{w1} = \frac{C_{b1}}{k^2} + \frac{1 + C_{b2}}{\sigma}$	0.3	2.0

The Minter-SST model is a combination of k-ε and k-ω turbulence models.

$$\begin{cases} \dfrac{\partial \rho k}{\partial t} + \nabla(\rho k u) = \nabla\left[(\mu + \sigma_k \mu_t)\nabla k\right] + P_k - \beta^* \rho \omega k, \\ \dfrac{\partial \rho \omega}{\partial t} + \nabla(\rho \omega u) = \nabla\left[(\mu + \sigma_\omega \mu_t)\nabla \omega\right] + \gamma \dfrac{\rho}{\mu_t} P_k - \beta^* \rho \omega^2 + (1 - F_1) D_{k\omega}. \end{cases} \quad (3)$$

Here k is the kinetic energy; ω is the specific dissipation rate. The rest of the functions and constants were shown in article [13,14].

Where

$$S_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} - \frac{\partial u_j}{\partial x_i}\right),$$

$$P_k = \tau_{ij} \frac{\partial u_i}{\partial x_j},$$

$$\tau_{ij} = \mu_t (2S_{ij} - \frac{2}{3}\frac{\partial u_k}{\partial x_k}\delta_{ij}) - \frac{2}{3}\rho k \delta_{ij}.$$

and turbulent viscosity is related to the turbulence energy and dissipation rate as follows:

$$\mu_t = \frac{\rho a_1 k}{\max(a_1 \omega, \Omega F_2)}.$$

Each of the constants is a mixture of inner 1 and outer 2 constants, mixed through:

$$\phi = F_1 \phi_1 + (1 - F_1)\phi_2.$$

Where ϕ1 represents the constant 1 and ϕ2 is a constant 2.

Additional functions are set:

$$F_1 = \tanh(\arg_1^4),$$

$$\arg_1 = \min\left[\max\left(\frac{\sqrt{k}}{\beta^* \omega d}, \frac{500v}{d^2 \omega}\right), \frac{4\rho\sigma_{w2} k}{CD_{kw} d^2}\right],$$

$$CD_{kw} = \max\left(2\rho\sigma_{w2}\frac{1}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j}, 10^{-20}\right),$$

$$F_2 = \tanh(\arg_2^2),$$

$$\arg_2^2 = \max\left(2\frac{\sqrt{k}}{\beta^* \omega d}, \frac{500v}{d^2 \omega}\right),$$

$$\gamma_1 = \frac{\beta_1}{\beta^*} - \frac{\sigma_{w1} k^2}{\sqrt{\beta^*}}, \quad \gamma_2 = \frac{\beta_2}{\beta^*} - \frac{\sigma_{w2} k^2}{\sqrt{\beta^*}}.$$

and ρ represents the density,νt=μt/ρ is the turbulent kinematic viscosity, μ is the molecular dynamic viscosity, d - the distance from the field point to the nearest wall and

$\Omega = \sqrt{2W_{ij}\,2W_{ij}}$. vorticity magnitude, c $W_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} - \frac{\partial u_j}{\partial x_i}\right)$.

The rest of the values are constants of the model and are presented in (tab. 2) [4].

Table 2. Constants of the SSTmodel

σ_{k1}	σ_{k2}	β^*	σ_{w1}	σ_{w2}	k	β_1	β_2	a_1
0.85	1.0	0.09	0.5	0.856	0.41	0.075	0.0828	0.31

Here are some specific examples illustrating the properties of the SA and SST models briefly described above. Figure 1 shows a comparison of the SA and SST models with the experimental data [15] for the dimensionless excess velocity and temperature profiles in the main section of the axisymmetric jet in the cocurrent flow.

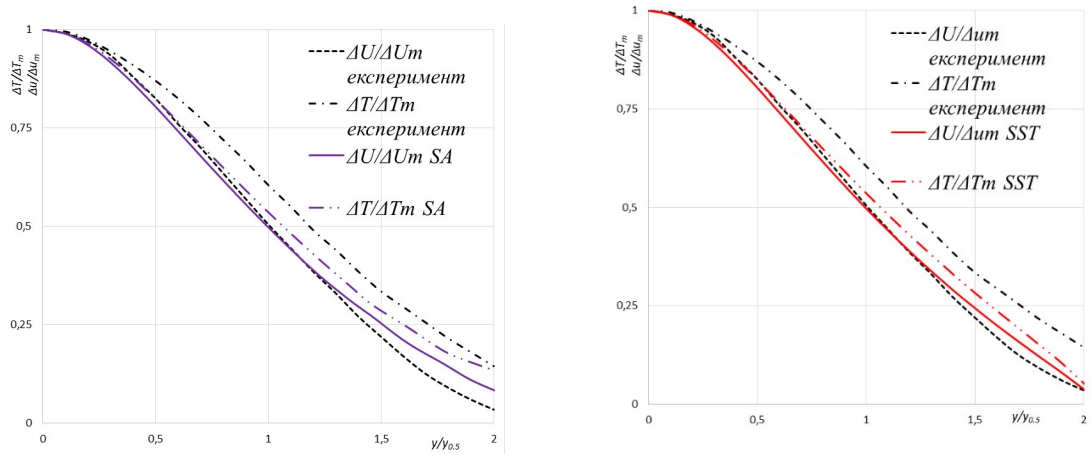

Fig. 1. Comparison of the SA (right) and SST (left) models with experimental data [16-18] on the dimensionless profile and excess velocity and temperature in the main section of the axisymmetric co-flow

Conclusions

A comparative analysis of the numerical results of two standard SA and SST turbulence models shows that they describe well the processes of momentum and heat transfer. Therefore, they can be used to solve engineering problems.

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