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RESEARCH ARTICLE

Investigation of Numerical Analysis Velocity Contours k-ε Model of RNG, Standard and Realizable Turbulence for Different Geometries

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HIGHLIGHTS

> Fluid flow is divided into two main categories (laminar or turbulent) related to forces (inertia, viscose, etc.). laminar and turbulence flows are also important in computational fluid dynamics (CFD).

> Apart from laminar behavior, turbulent flows involve several obstacles and therefore require hard efforts during experimental and quantitative studies. Turbulence is an unstable type of fluid flow that is highly irregular in space and time, three-dimensional, diffuse in terms of rotation, energy and high Reynolds numbers.

> Which turbulence model is suitable for CFD analysis is a distressing situation and can sometimes lead to incorrect solutions. It is necessary to select an appropriate model and simulate the physical event as accurately as possible.

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ABSTRACT

In this research article, three (k-ε) turbulence models, (Standard k-ε), (RNG k-ε) and (Realizable k-ε) were compared. The turbulent flow characteristics are illustrated in three-dimensional geometry using the ANSYS FLUENT 18.0 coded turbulence model. Numerical results were verified by comparison with the results of computational fluid dynamics (CFD). Their speed is resolved according to the computational fluid dynamics (CFD) and velocity profiles, turbulent kinetic energy profiles confirmed numerical results. Also, the contour of the flow rate and the vectors shown. One of the most interesting observations of numerical solutions compared to CFD data is that k-ε varieties have a valid estimate of flow properties that are far from wall effects.

Contents

1. Introduction

Nowadays, as fast computer performance increases, the complex and difficult geometries of engineers are calculated and simulated easily. By solving numerically combined partial differential equations, PDEs for continuity, momentum and energy equations using one of the modern Computational Fluid Dynamics, CFD codes have become a common and more powerful tool in the most modern industrial fields. CFD codes distributed a large number of such complex PDEs into algebraic equations and then

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obtained numerical solutions using the numerical one. The predicted functions and design of different interesting engineering problems in engineering areas and even in medical fields are quantified and the experimental setups are established according to it. Any advanced technique, equipment or the engineer-related machine will no longer be marketed until performance or function is simulated without using one of the CFD codes.

Flow in the fluid dynamics is divided into three categories: 1-laminar flow, 2-temporary flow, and 3-turbulent flow. Turbulent flow is one of the most common flows in most practical engineering systems, and each flow pattern is dominated by unique flow characteristics. The Reynolds number is defined as the ratio of the inertial force to the viscous force of the liquid flow, and this number is the key to distinguish between the flow models. In turbulent flow, many fluid dynamics events occur. The disturbances in the fluid movement and the fluctuation of the fluid velocity rapidly convert the flow to turbulent flow. Eddies and vortices will be formed due to the chaotic and unstable state of the turbulent movement of the flow particles. Large vortices and small vortices with different turbulent scales, length scales and timescales will be transferred in the direction of flow under the vortex stretching process, so the flow will be turbulent. For various flow types, many types of turbulence are evolving. It is very important to understand these models of turbulence to use them appropriately to model flow events. Tu.et.al [1] used a comparison problem to compare two turbulence models in three commercial CFD codes.

There are two tuned k-ε family models, the Renormalization Group, the RNG k-ε model and the feasible k-ε model. These two alternative turbulence models of the standard k-ε model were used by Yakhot et al. [2] and Shih at al. [3], respectively, in order to develop the numerical estimations in which the standard k-ε model failed. Then Morán-López [4] due to the interactions between differently sized swirl based on the concept of non-equilibrium energy transfer have solved a spectral dispersion rate equation. In more comfortable and high-speed applications, numerical estimates of Shock/Turbulent Boundary Layer Interaction (STBLI) flows were generally verified using the Reynolds averaged Navier-Stokes (RANS) method [5, 6]. Sinha et al. [7] examined the physics of the motion of a shock wave and examined the standard k-ε they had drawn the model. K and ε the equations may lead to the model parameters, the functions of the reverse flow Mach number which is normal from the shock.

RANS and Large Eddy Simulation equations (LES) are the common ones that require a compatible amount of resources during examination against Direct Numerical Solution (DNS). The LES method is one of the valid numerical methods for solving fluid flow. The LES method was first introduced in 1963 and was then used for meteorological surveys. From the practical point of view, this approach can be considered as a bridge between RANS and DNS. The RANS method is known as a valid method for solving fluid flow; however, its application in time-dependent flows does not provide sufficient information on fluid behavior. Despite the high precision of DNS, it has many problems in solving geometries or complex states, and in some cases, it is impossible to use it.

Due to the importance of turbulent flow in mechanical engineering and the fluidity of the fluid, in this article, we are going to introduce models of turbulent flows.

2. Material and Method

The k-ϵpsilon model is one of the most common types of turbulence models but does not work well in large reverse pressure gradients. This includes two extra transport equations to represent the model, i.e. the turbulence characteristics of the flow. A turbulence model is a computational procedure for closing the system of equations of the average flow, so that more or less a large part of the flow problems can be solved. For most engineering issues, it is not necessary to solve the details of the turbulent fluctuations and usually, only the effects of turbulence flow on the flow medium are considered. In general, the role of turbulent flow model in solving the Reynolds stresses provides a model for turbulent viscosity.

The most common models of turbulence are categorized as follows:

- Equivalent zero models: such as the Model of the Perinatal Mixture
- Single-equivalence models: such as the Spallart-Almaras model
- Two-equation models: such as versions of the k-w and k-ϵ models
- Algebraic Stress Model
- Reynolds Stress Model: Includes 7 equations in three-dimensional coordinates and 5 equations in two-dimensional coordinates.

Currently, classic mixing and k-ϵ models are widely used. The basis of these models is the initial assumption that the similarity between viscous stresses and Reynolds stresses is in the mean flow. Both stresses on the right of the equation have the size of motion, and in Newton's law of viscosity, the viscosity stresses are proportional to the rate of deformation of the fluid element:

$$\tau_{ij} = \mu(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_i}{\partial x_i}) \quad (1)$$

The basis of the LES method is direct solving large scale and microscale modeling. This is based on two basic principles: first, the losses in large vortices are low and carry more energy and therefore it is more important. Second, small vortex modeling is very easy due to the magnitude of their dimensions and their behavior. Due to the sensitivity of the relationship between these two parts, called the energy cascade, this relationship is associated with the modeling of the small scale, but the LES method has problems in the modeling of known properties (even in the neutral type). Because, while the propagation of many properties at the leaky scale occurs, the LES method only solves large scale scales. The simulation of the transfer equations is also made into one of the methods called subnet models. Using the subnet models, we can solve the transport equations and calculate the instantaneous values.

In Reynolds values higher than Re>70000 due to intense mixing processes, there is a significant change in the flow behavior. Eventually, the flow behavior is random and irregular and, even with constant boundary conditions, becomes completely non-linear. This area is called a disturbed area, which is shown in Figure 1.

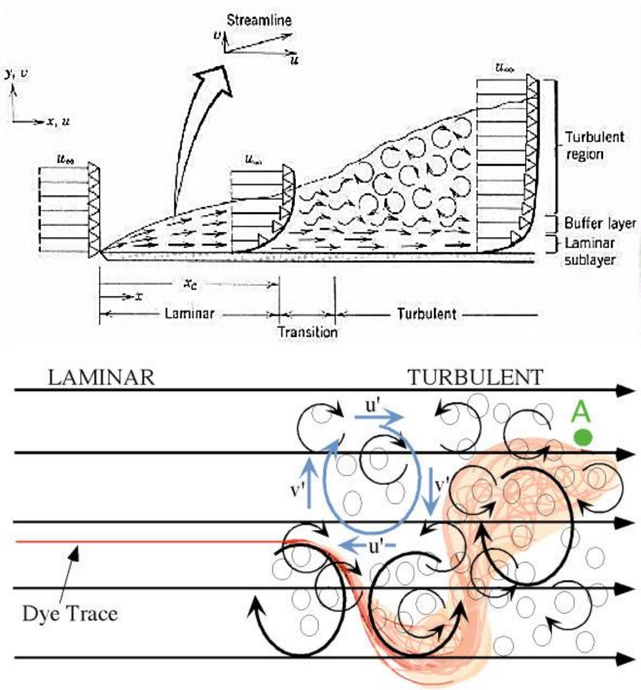

Figure 1 A Sample of Measured Turbulent Flow Rate [8]

The random nature of the turbulent flow prevents the full (momentary) examination of all fluid particles. Instead, instantaneous velocity of the turbulent flow can be divided into two parts: the mean value U and the oscillatory value (u'). The best mode for turbulent flow modeling is to investigate the turbulent flow with the mean value of the flow properties (U, V, W, P, etc.) And specify the statistical properties of fluctuations (u ', v', w ', p', etc.). In a turbulent flow of turbulent fluctuations, they always have three-dimensional behavior. In addition, according to the following diagram, the turbulent flows show a rotating flow structure. This rotating flow structure is called turbulent eddy.

Fluid particles that are widely spread at first can be rotated by rotational motion. As a result, heat transfer, mass and movement size increase effectively. For example, in the form shown above, a colored band placed at a disturbing flow point is rapidly lost along the current. Such an effective mixing results in a large increase in the amount of heat penetration, mass, and size of movement (larger vortices, called "Vortex Stretching"), take energy from the fluid flow or lose energy. In a turbulent flow, small mediums are dramatically drained by larger eddies and weakened by the mean flow. As shown in Figure 2, the kinetic energy of the larger entities is transferred to smaller and smaller ones and eventually fades away, which is called the energy cascade.

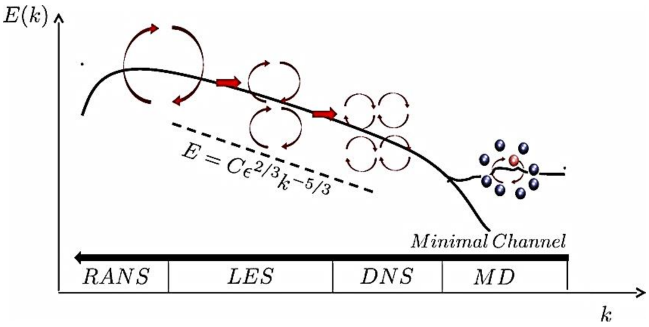

Figure 2 Conversion of Kinetic Energy from Large Edits to Smaller and Smaller Editions (Energy Cascade)

The above figure shows a comparison between three views of turbulent flow modeling, the LES, RANS, and DNS views. In the traditional RANS view, all turbulent flow scales are modeled using turbulence models such as k-ε, or RSM. As a result, there is no need to use very small networks and it is economically computable. In contrast, there is a DNS, which solves all of the scales directly to the length of the Kolmogorov scale. Therefore, in order to take into account all details of the small vortices, it needs a very small network and the cost of its calculation is very large.

Therefore, despite the development of parallel processing knowledge and the availability of very powerful equipment in advanced countries, the use of the DNS viewpoint is limited to simple issues with the average Reynolds. To solve this problem, the LES view, by defining the size of the filter around the dimensions of the largest vortices, directly solves the scales larger than the filter size, and models smaller scales using different methods. This has two advantages. First, small vortices exhibit less or more identical behavior in different situations and do not flow through the geometry. Therefore, the accuracy of modeling their behavior is much more than the accuracy of the modeling of the whole spectrum of energy. The second advantage is that due to the filtering of the survival equations and the use of modeling techniques for scales smaller than the filter size, there is no need for a very fine mesh, such as that used in the DNS view. As a result, their calculations are far more economical than DNS calculations, and today, with the development of parallel processing technology, it is possible to apply the LES perspective to real and complex systems.

Turbulent flows are one of the important topics in the fluid trend, which can be designed and simulated using Fluent and OpenFOAM software.

Reynolds Stress could be written as follows:

$$\tau_{ij} = -\rho\overline{u_i'u_j'} = \mu_t\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_i}{\partial x_i}\right) - \frac{2}{3}\rho k\delta_{ij} \quad (2)$$

The right side of this relationship, with the exception of the appearance of turbulence viscosity, is the same as in equation (1). The second term of the right-hand side of the above equation includes the Delta Chronecker, which relates to the effects of Reynolds stresses. Heat transfer, mass, and other disturbed scalar properties are simulated similarly.

The above relation shows that the transfer of turbulent flow size is assumed to be compatible with the velocity slope. Using similarity, disturbance transitions consider a scalar quantity proportional to the slope of the mean value of the transmitted quantity:

$$-\rho\overline{u_i'\varphi'} = \Gamma_t \frac{\partial \varphi_i}{\partial x_i} \tag{3}$$

where Γ_t is turbulent or eddy diffusivity. Since the turbulent transfer of motion size, heat, and mass are due to the same function, that is, the mixing of vortices, we expect the turbulent diffusion coefficient Γ_t to depend on the amount of turbulence viscosity. This hypothesis is well known as the Reynolds analogy, which leads to the definition of the Schmidt number and the turbulent Prandtl as follows:

$$\sigma_t = \frac{\mu_t}{\Gamma_t} \tag{4}$$

In many experiments, it has been shown that these numbers (Schmidt disturbed when Γ_t is considered to be equal to the turbulent mass diffusion coefficient (σ_t) and the turbulent penetration when Γ_t is considered to be equal to the attenuation coefficient is almost constant.

The turbulence model should provide a link to calculate turbulence viscosity. The model of the mixing length describes the stresses using a simple algebraic formula for (μ_t) and as a function of the location. The k-ε model is a perfectly complete model that is used to describe disturbance for z and is useful for transferring disturbance properties by displacement and penetration, as well as for calculating the generation rate and loss of disturbance. In the k-ϵ model, two transmission equations, one for the turbulent kinetic energy generation rate k and one for the turbulent kinetic energy dissipation rate ϵ, are solved simultaneously. An important assumption in both models is that turbulent viscosity (μ_t) is isotropic. That is, the ratio between Reynolds stresses and the average rate of deformation is the same in all respects. In other words, the rate of oscillation is assumed to be the same in all directions. This assumption is violated in many cases involving complex currents. To solve this problem (applying different fluctuations in different directions) we must extract the transfer equations for each Reynolds stress and then solve this equation, which leads to the development of the RSM disturbance model. In the RSM model, an equation is obtained for each Reynolds stress, and as a result, six other equation transfer equations are added to the set of equations. As a result, the RSM model is much more expensive than other models of turbulence. Solve six equations in the model, compared with the k-ϵ simulation shows a substantial increase in price. In contrast to RSM, the Algebraic Stress Model (ASM) is an economical way of using the RSM model. In fact, the ASM model can be considered at a lower cost for non-isotropic effects. Given that the model RSM large volume of calculations because the Reynolds stress terms are created, if the terms of the movement and influence delete or otherwise approximated this model to a system of algebraic equations become to solve and simpler is less expensive.

2.1. Transport equations for the standard k-ϵpsilon model

For turbulent kinetic energy k:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + P_k + P_b + \rho\epsilon - Y_M + S_k \tag{5}$$

For dissipation ϵ :

$$\frac{\partial}{\partial t}(\rho \epsilon) + \frac{\partial}{\partial x_i}(\rho \epsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial \epsilon}{\partial x_j}\right] + C_{l\epsilon}\frac{\epsilon}{k} + (P_k + C_{3\epsilon}P_b) - C_{2\epsilon}\rho\frac{\epsilon^2}{k} + S_\epsilon \tag{6}$$

2.2. Realizable k-ϵpsilon model

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + P_k + P_b + \rho\epsilon - Y_M + S_k \tag{7}$$

$$\frac{\partial}{\partial t}(\rho \epsilon) + \frac{\partial}{\partial x_j}(\rho \epsilon u_j) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial \epsilon}{\partial x_j}\right] + \rho C_1 S_\epsilon - \rho C_2 \frac{\epsilon^2}{k+\sqrt{\vartheta\epsilon}} - C_{1\epsilon}\rho\frac{\epsilon^2}{k}C_{3\epsilon}P_b + S_\epsilon \tag{8}$$

Where

$$C_1 = \max[0.43, \frac{\eta}{\eta+5}] \ , \ \eta = S\frac{k}{\epsilon} \ , \ S = \sqrt{2S_{ij}S_{ij}} \tag{9}$$

RNG k-ϵpsilon model

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial t}(\rho k u_,) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial k}{\partial x_j}\right] + P_k + \rho \tag{10}$$

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial t}(\rho \epsilon u_,) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial k}{\partial x_j}\right] + C_{1\epsilon}\frac{\epsilon}{k}P_k - C_{2\epsilon}^*\rho\frac{\epsilon^2}{k} \tag{11}$$

Where

$$C_{2\epsilon}^* = C_{2\epsilon} + \frac{C_\mu \eta^3(1-\eta/\eta_0)}{1+\beta\eta^3} \tag{12}$$

And

$$\eta = SK/\epsilon \quad \text{and} \quad S = (2S_{ij}S_{ij})^{1/2} \tag{13}$$

In the RNG model, the values of all constants are commonly used for comparison with the standard k-ϵpsilon equation for comparison [2]:

C_μ=0.0845(0.09)

σ_k= 0.7194(1.0)

σ_ϵ= 0.7194(1.30)

$C_{\epsilon 2}$=1.42(1.44)

η_0=4.38

β=0.012

3. Results

The simplest model of the image is the Standard k-ϵ model, and the reason why this model-transport equation exists everywhere is that both models are the same. The standard k-ϵ model in FLUENT has been studied in this class of turbulence model and has been studied into applied engineering flow calculations (CFD) since proposed by Launder and Spalding [9] . The robustness and economy for a wide variety of turbulent flows are reasonable and it is considered one of the most popular models in industrial flow and heat transfer simulations. It is a semi-empirical model and in this model, the derivation of the equations is based on phenomenological and experimental ideas. The strengths and weaknesses of the standard k-ϵ were determined and improvements were made to the model to improve performance. Two of these variants are available in the FLUENT: they investigated the RNG k-ϵ model and the feasible k-ϵ model.

The RNG k-ϵ model is a rigorous statistical technique model and is considered the renormalization group theory. It is similar to the standard k-ϵ model, but includes the following fixes:

> In the RNG model, the equation of (epsilon) has an additional term that significantly increases the accuracy of the rapidly stretched flows.

> The vortex effect on turbulence is included in the RNG model, which increases directly for the flow in the rotation.

> The RNG theory provides a convenient and practical formula for the turbulent Prandtl numbers, but the standard k model has been given constant values previously determined by ourselves.

> In the standard k-ϵ model, even if there is a high Reynolds numbered model, the RNG theory will emerge as a differential formula analytically derived for effective viscosity with a low Reynolds effect. However, the effective use of this property causes it to be handled appropriately in the regions close to the walls.

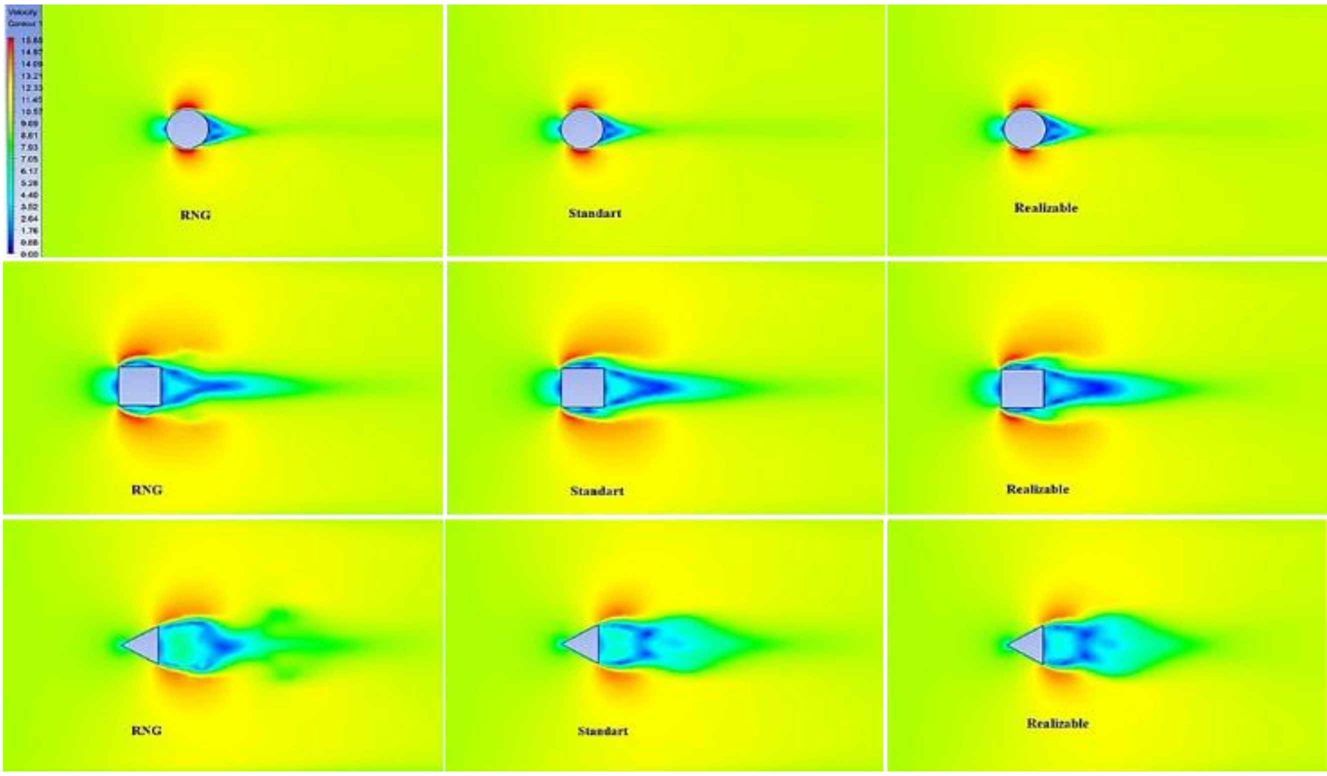

Figure 3 Velocity Contours of Various K-ε Family Models

As shown in Figure 3, these features may prove that the RNG k-ϵ model is a more accurate and reliable method for a larger flow class than the standard k-ϵ model.

As shown in Figure 3, the realizable k-ϵ model is a relatively new development and offers two significant differences from the standard k-ϵ model:

> As a result of research and numerical solutions, the realizable k-ϵ model produces a new function for turbulent viscosity.

> For the velocity distribution ratio, a new transport equation is derived and extracted from a full frame for the transport of the mean square vorticity fluctuation.

The term of realizable in the turbulence model, the model means a few mathematical constraints on the Reynolds stresses consistent with the physics of the turbulent flows, in other words, the statements taken in this case can be carried out neither in the standard k-ϵ model nor in the RNG k-ϵ model.

4. Conclusions

In this study, we have computationally calculated the k-ϵ turbulence model in 3 types of geometry (cylindrical, square and triangle) and in a virtual air tunnel, and as a result an immediate benefit of the realizable k-ϵ model is the more accurate estimation of the propagation speed of both planar and round jets. The k-ϵ model is proposed for the realistic model of the flowing fluid, including the geometry and actual performance of the lower layers.

Both models (realizable and RNG k-ϵ models) showed significant improvements in the standard k-ϵ model, in which the flow characteristics of the flow properties, as shown in the figures, included curvature, vortices and geometry. However, initial studies have shown that the realizable model provides all k-model versions and the best-performing model in various geometries for several validations of discrete streams and streams with complex secondary flow characteristics.

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