Journal of Hydrodynamics, Ser. B, 4 (2001), 98 - 101
China Ocean Press, Beijing - Printed in China

SIMULATION OF 3-D FLOW AROUND A VAN-BODY TRUCK WITH RNG k-ε TURBULENCE MODEL

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(Received Dec. 5, 2000)

ABSTRACT: In this paper it is proved that the calculation precision of the outside flow field of the van-body truck using RNG k-ε turbulence model is higher than that using standard k-ε turbulence model by means of experiments. The calculation results of the outside flow field of a certain domestic van-body truck are given. And by analyzing and comparing the different tail flow plots, the tail flow structural characteristics and the relationship between the position and the intensity of the tail vortex and the aerodynamic drag is obtained, which can direct the design of the outside aerodynamic shape of the van-body truck.

KEY WORDS: van-body truck, RNG k-ε model, numerical simulation

1. INTRODUCTION

The van-body truck is a blunt body with irregular shape, and the van body is much higher than the driver cab, which results in the large upwind area, the worse aerodynamic characteristics and the large aerodynamic drag. With the increase of the vehicle speed the fuel consumption increases greatly and the driving stability becomes worse. Therefore, improving the aerodynamic characteristics of a van-body truck not only decreases the fuel consumption but also causes great benefits in many other ways.

At present there are mainly two ways to research the automobile aerodynamics, the wind tunnel experiment and the numerical simulation. The objects of the later are mainly cars[1~2], while the numerical simulation of a van-body truck has not been reported except that the author has simulated the surface airflow of a certain home-made van-body truck with the standard k-ε turbulence model[3~4]. The model has brought great effects on the engineering turbulence calculation since it appeared more than 20 years ago. But because of its limitations, the calculation error will be larger if it is used in the numerical simulation of van-body truck, for which there exist serous separating flows.

In this paper, the RNG k-ε turbulence model is applied to the 3-D flow numerical simulation of a van-body truck in order to examine its abilities of predicting the 3-D flow field around a van-body truck by comparing calculation results with the experimental data.

2. MATHEMATICAL MODEL OF THE 3-D FLOW FIELD AROUND A VAN-BODY TRUCK

2.1 *Governing equations for 3-D flow field*

Considering the incompressibility of airflow around the truck, we can use the N-S equation equations described as follows:

Continuity equation

$$\frac{\partial u_i}{\partial x_i} = 0$$

Momentum equation

$$\rho\frac{\partial(u_i u_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i}\delta_{ij} + \frac{\partial}{\partial x_j}\left[\mu_e\left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right)\right]$$

where ρ is the density fluid, u_i is the fluid velocity, $i = 1, 2, 3$ represents the three directions in Cartesian coordinates, p is the pressure of the fluid, $\mu_e = \mu + \mu_t$ the effective viscosity, $\mu_t = \rho C_\mu k^2/\varepsilon$ the turbulence viscosity, and δ_{ij} is the Kronecker symbol.

2.2 *RNG k-ε model*

RNG k-ε model based on Renormalization Group (RNG) methods proposed by Yakhot and Orszag (hereafter denoted YO)[5]. The RNG procedure of YO gives rise to a set of equations having the attractive feature with no undetermined constants, and the built-in corrections that allow the use of the model in both high-and low-Reynolds-number regions of the flow. At high Reynolds numbers the RNG k-ε model of YO is of

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the same general form as the standard k-ε model, except that the model constants are calculated explicitly from the RNG analysis and assume somewhat different values. And the additional term in the RNG k-ε model equations becomes significant for flows at large strain rate. The resulting high-Reynolds-number form of the RNG k-ε model proved successful for the calculation of a number of separated flows. Also it is used conveniently because its coefficitents can be obtained by means of theoretical calculations and emerged apparently in the equations.

The RNG k-ε turbulence kinetic energy equation is

$$\frac{\partial(\rho u_i k)}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\alpha_k \mu_e \frac{\partial k}{\partial x_j}\right) + \mu_t S^2 - \rho\varepsilon$$

The dissipation rate equation is

$$\frac{\partial(\rho u_i \varepsilon)}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\alpha_\varepsilon \mu_e \frac{\partial \varepsilon}{\partial x_i}\right) + C_{1\varepsilon}\mu_t S^2 - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} + S_\varepsilon$$

where k is turbulence kinetic energy, ε dissipation rate.

The variable S and the additional source term S_ε in the model equations are defined respectively as

$$S = \sqrt{2S_{ij}S_{ij}}, \quad S_\varepsilon = -\rho C_\mu \eta^3 \frac{1 - \eta/\eta_0}{1 + \beta\eta^3}\frac{\varepsilon^2}{k}$$

where

$S_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$, and the dimensionless parameter $\eta = \frac{Sk}{\varepsilon}$.

The empirical coefficients in high-Reynolds-number region are listed in Table 1. Note that all the variables of the equations have been taken time-averaged values.

Table 1 Values of constants in RNG k-ε model

C_μ	α_k	α_ε	$C_{1\varepsilon}$	$C_{2\varepsilon}$	η_0	β
0.0845	0.1393	0.1393	1.42	1.68	4.38	0.012

2.3 *Calculations*

The general software Phoenics 3.3 was used to the simulation. The grid setting, boundary conditions, the van-body truck model and other coefficients, were presented in Refs. 3～4, and omited here. The contents of calculations are the variations of the flow field around a van-body truck and the drag coefficient when the height of the van- body and the gap between cab and van change.

3. CALCULATION RESULTS AND ANALYSIS

3.1 *Comparison of the results of the RNG k-ε model and the standard one with experimental data*

Fig. 1 shows the pressure distribution on the central symmetrical section of the van-body truck, where the dotted line the results from the standard k-ε model, experiments and calculations with RNG k-ε model. It can be seen in Fig. 1 that the results from RNG k-ε coincide to those from experiments better than those from standard k-ε model. As a result, it can be concluded that the RNG k-ε model has higher precision than the standard k-ε model in simulating the flow field around the van-body truck.

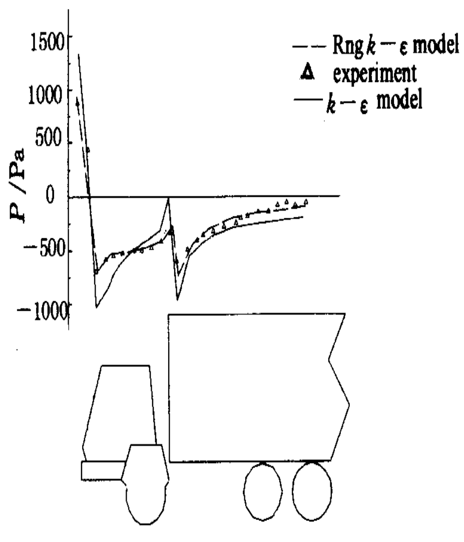

Fig. 1 Pressure distribution on the central symmetry section of the van-body truck

The drag coefficient C_x is listed in Table 2 in the case of the height H of van and the gap D between van and cab varying. From this table it is found that the results from RNG k-ε model are much closer to experimetnal data than those from standard k-ε model at different structural coefficients. According to the above comparison we can find that the RNG k-ε model is superior to the standard k-ε model in predicting the 3-D surface flow field of the van-body truck.

3.2 *Results from RNG k-ε model analysis*

Fig. 2 and Fig. 3 are a calculation example at cer-

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tain structural coefficients , in which the flow

Table 2 **Aerodynamic drag coefficients at different structural coefficients**

Hight (mm)	Gap (mm)								
	30			40			50		
	1	2	3	1	2	3	1	2	3
340	0.687	0.593	0.587	0.684	0.587	0.575	0.681	0.590	0.575
350	0.694	0.640	0.633	0.690	0.612	0.608	0.686	0.600	0.588
360	0.669	0.654	0.652	0.694	0.659	0.648	0.689	0.634	0.625

vectors on the central symmetry section of the van-body truck are shown in Fig. 2 and the isobars on the central symmetry section are shown in Fig. 3.

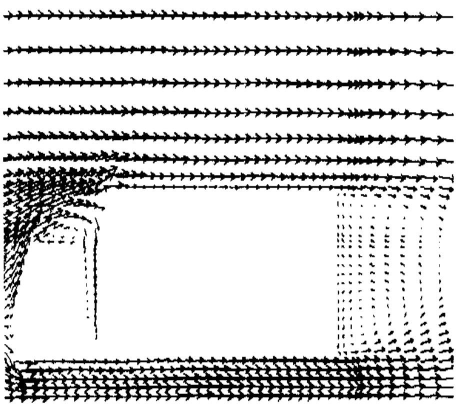

Fig. 2 Flow vector plot on the central symmetry section

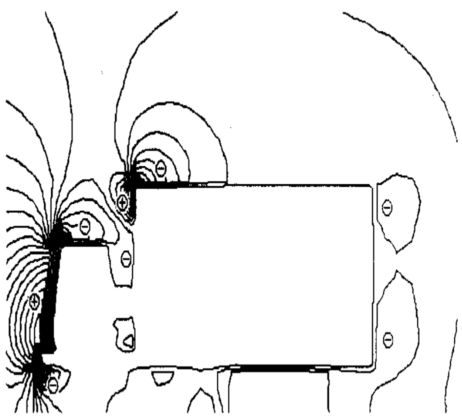

Fig. 3 Isobar plot on the central symmetry section

The calculations indicate that , when airflows over the surface of the van-body truck , the airflow in front meets with the head of the truck and blocked by it , and the positive pressure is relatively high. Thus the airflow is divided all around under the action of higher pressure. The upper airflow is induced into separation at the upper-fore verge of the driver cab. Then a large airflow separation region with a powerful vortex is formed over the driver cab. Because the vortex whirling consumes lost of energy , the pressure decreases. So there is a negative pressure region over the driver cab. This region will raise the aerodynamic lift of the truck , which is disadvantageous for the stability of the truck. The high-speed airflow which flows over the cab strike the front side of the van that is higher than the driver cab , forms a positive pressure region. Simultaneously it also can be seen that a part of the airflow flows down the gap between the driver cab and the van , and the other goes round the upper-fore verge of the van , emerging separation flow and being induced into vortex. So the pressure in this region is negative. With the airflow flowing backward , the vortex weakens little by little , the negative pressure declines subsequently , then the airflow flows backward adherent to the top of van , and at last it converges into the tail flow.

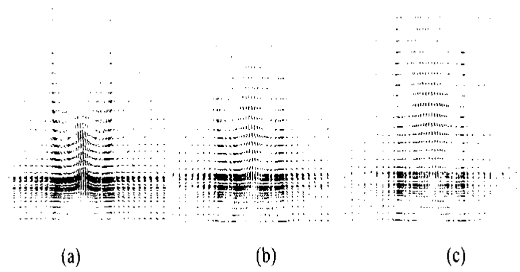

Fig. 4 Velocity vector plots on the grid $ix = 8$, 16 , 24 plates away from the van in the tail flow respectively

Fig. 4 a ,b and c are respectively the velocity vector plots on the fore , middle and rear sections of the tail flow. From Fig. 2 and Fig. 4 , can be that the tail flow of the van-body truck is a complicated vortex region , including the down-curling one formed by the airflow over the truck , the upper-curling one formed by the airflow under the truck and the spiral flow region formed by the airflow of both sides of the van. On

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the central symmetrical section, the pressure of the tail flow is low, the velocity of the flow from the top is high and the pressure of the airflow under the truck is higher than that of the tail flow, the upper and down curling vortex regions emerge in the rear of the truck. This accords well with the experimental results[6]. From Fig. 4 a, b and c the longitudinal change of the tail vortex structure can be seen clearly. On the fore sectional of tail flow, there exist two pairs of the vortex, one is higher on the van and the other is down close to the ground. The former is the spiral flow that emerges from the higher-speed flow of both sides of the van attracted by the negative pressure in the tail flow when flowing into the tail flow. And the latter is the one induced by the vehicle wheels. As shown in the plots of sections b and c, the position of the vortex centers moves to both sides and its inflence region widens with the vortex extending backwards. This tail flow plots are simialr to that of the rear flow of cars[7].

4. CONCLUSIONS

(1) The calculation of the van-body truck with the RNG k-ε model is more exact than that of the standard k-ε model. It is of great value for predicting the aerodynamic characteristics around the van-body truck and assisting the aerodynamic characteristics around the van-body truck and assisting the aerodynamic molding of van-body truck.

(2) There are two pairs of obvious drag vortexes in the tail flow of the van-body truck, whose center positions move towards both sides. The influence region widens, and the intensity declines with its extending backwards.

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