rectly simulated," thereby explaining the poor correlation between prediction and experiment in Fig. 1 of Ref. 1. The only concensus appears to be that more research is needed, research in which close cooperation between theoreticians and experimentalists, of the type discussed in Ref. 8, will be sorely needed.

References

[1]Hung, C.-M., "Comment on 'Critique of Turbulence Models for Shock-Induced Flow Separation,' " *AIAA Journal*, Vol. 29, 1991.

[2]Ericsson, L. E., "Critique of Turbulence Models for Shock-Induced Flow Separation," *AIAA Journal*, Vol. 27, Nov. 1989, pp. 1648–1650.

[3]Hung, C. M., "Computation of Three-Dimensional Shock Wave and Boundary-Layer Interactions," NASA TM 86780, August 1985.

[4]Dolling, D. S., "Comparison of Sharp and Blunt Fin-Induced Shock Wave/Turbulent Boundary-Layer Interactions," *AIAA Journal*, Vol. 20, Oct. 1982, pp. 1385–1391.

[5]Knight, D., Horstman, C. C., Ruderich, R., Mao, M.-F., and Bogdonoff, S. M., "Supersonic Turbulent Flow Past a 3-D Swept Compression Corner at Mach 3," AIAA Paper 87-0551, Jan. 1987.

[6]Knight, D., Raufer, D., Horstman, C. C., and Bogdonoff, S. M., "Supersonic Turbulent Flow Past a Swept Compression Corner," AIAA Paper 88-0310, Jan. 1988.

[7]Horstman, C. C., "Prediction of Secondary Separation in Shock Wave Boundary-Layer Interactions," *Computers and Fluids*, Vol. 17, Nov. 4, 1989, pp. 611-614.

[8]Bogdonoff, S. M., AIAA Paper 90-0766, Jan. 1990.

Comment on "New Eddy Viscosity Model for Computation of Swirling Turbulent Flows"

Gary C. Cheng*
University of Kansas, Lawrence, Kansas 66044

IN recent comments on Kim and Chung's[1] new eddy viscosity model by Gessner[2] and Leschziner[3] and a reply by Kim and Chung,[4] the determinations of modeling constants and the value of the turbulent kinetic energy production to dissipation ratio were argued. Kim and Chung implemented the k-ϵ model by deriving an algebraic equation for eddy viscosity based on the algebraic Reynolds stress model proposed by Rodi.[5] In Rodi's model, the equation is

$$\frac{\overline{u_i u_j}}{k} = \phi_1 + \frac{P_{ij}}{\epsilon} + \phi_2 \delta_{ij} \tag{1}$$

where

$$\phi_1 = \frac{1 - C_2}{(P_r/\epsilon) + C_1 - 1} \tag{2}$$

$$\phi_2 = \frac{2}{3}\frac{C_2(P_r/\epsilon) + C_1 - 1}{(P_r/\epsilon) + C_1 - 1} = \frac{2}{3}\left[1 - \frac{P_r}{\epsilon}\phi_1\right] \tag{3}$$

δ_{ij} is a Kronecker delta, P_{ij} the production tensor of the Reynolds stresses $\overline{u_i u_j}$, P_r the production of the turbulent kinetic energy k, ϵ the isotropic dissipation rate, C_1 the inertial return-to-isotropy constant, and C_2 the forced return-to-isotropy constant.

Received March 26, 1990; accepted for publication May 26, 1990.

*Graduate Research Assistant, Aerospace Engineering Department; currently Research Scientist, SECA, Inc., Huntsville, AL. Member AIAA.

After some elaborate manipulation, Kim and Chung obtained an expression for the eddy viscosity ν_t:

$$\nu_t = \frac{\alpha}{1 + \beta R_i}\frac{k^2}{\epsilon} \tag{4}$$

where

$$R_i = \frac{k^2}{\epsilon^2}\frac{W}{r}\frac{\partial W}{\partial r} \tag{5}$$

$$\beta = 4\phi_1^2 \tag{6}$$

$$\alpha = \phi_1\phi_2 = \frac{2}{3}\phi_1\left(1 - \frac{P_r}{\epsilon}\phi_1\right) \tag{7}$$

For the flow without swirl, R_i is equal to zero, and then the constant α can be determined by matching with $C_\mu(=0.09)$. Gessner argued about matching α with $C_\mu = 0.09$ for a flow in local equilibrium ($P_r/\epsilon = 1$), which is true for the presence of wall but not necessary for swirling free jet flows. In Gessner's comment, a systematic analysis was shown to decide the values of ϕ_1 and ϕ_2 (and so the modeling constants C_1, C_2) as $P_r/\epsilon = 1$. Kim and Chung, however, replied with a good argument that it is not necessary to let $P_r/\epsilon = 1$ in the process of determining the value of β. Kim and Chung may be able to choose β literally in order to fit the experimental data, but the ratio of P_r/ϵ obtained from choosing $\beta = 0.25$ is not equal to the one shown in their reply.

From Eq. (6), we know that $\phi_1 = 0.25$ if $\beta = 0.25$ is chosen, and so P_r/ϵ is computed to be 1.84 from Eq. (7) according to Kim and Chung's matching α with $C_\mu(=0.09)$. Surprisingly, in Kim and Chung's reply, a statement was made: "Our model constant $\beta = 0.25$ implicitly assumes that P_r/ϵ is about 0.8 for $C_1 = 1.8$ and $C_2 = 0.6$ or $C_1 = 3$ and $C_2 = 0.3$. And if $C_1 = 2.2$ and $C_2 = 0.55$, $\beta = 0.25$ implies that $P_r/\epsilon = 0.6$."[4] It is obvious that the value of P_r/ϵ is fixed according to Eqs. (6) and (7) if α and β are selected. Simple algebra shows that with three unknowns (C_1, C_2, and P_r/ϵ; or ϕ_1, ϕ_2, and P_r/ϵ) only three equations are required. Several combinations, therefore, can be used to solve the problem. In Kim and Chung's statement, the prescribed C_1, C_2, and β along with $\alpha = C_\mu = 0.09$ is definitely overspecified; the value of P_r/ϵ is not matched, unless they do not require $\alpha = C_\mu = 0.09$ proposed in their original paper.[1]

If we assume that Kim and Chung want to maintain $\alpha = 0.09$, then the following exercise will demonstrate the inconsistency of their statement. From Eqs. (2), (3), (7), and (8), for $C_1 = 1.8$ and $C_2 = 0.6$,[6] $P_r/\epsilon = 1.41$ and $\beta = 0.131$ are obtained; for $C_1 = 3$ and $C_2 = 0.3$,[7] $P_r/\epsilon = 1.58$ and $\beta = 0.153$ are obtained; for $C_1 = 2.2$ and $C_2 = 0.55$,[8] $P_r/\epsilon = 1.34$ and $\beta = 0.126$ are obtained. These results show that $P_r/\epsilon > 1$, which violates $0 < P_r/\epsilon \leq 1$ in the flowfield protested by Kim and Chung. The argument in Kim and Chung's reply can be valid only when $\alpha = C_\mu \neq 0.09$, which is inconsistent with their original approach.[1] The selection of $\beta = 0.25$ along with $C_1 = 1.8$ and $C_2 = 0.6$[6] or $C_1 = 3$ and $C_2 = 0.3$[7] implies that $P_r/\epsilon = 0.8$ and $\alpha = C_\mu = 0.133$, whereas $P_r/\epsilon = 0.6$ and $\alpha = C_\mu = 0.142$ are obtained by the specified $\beta = 0.25$ with $C_1 = 2.2$ and $C_2 = 0.55$.[8] If this is the case, then the good agreement of the result from the new eddy viscosity with experimental data cannot imply that the success is due to the inclusion of Richardson's number or the ad hoc change of the modeling constant C_μ.

References

[1]Kim, K. Y., and Chung, M. K., "New Eddy Viscosity Model for Computation of Swirling Turbulent Flows," *AIAA Journal*, Vol. 25, No. 7, 1987, pp. 1020–1022.

[2]Gessner, F. B., "Comment on 'New Eddy Viscosity Model for Computation of Swirling Turbulent Flows'," *AIAA Journal*, Vol. 27, No. 9, 1989, pp. 1035–1036.

[3]Leschziner, M. A., "Comment on 'New Eddy Viscosity Model for Computation of Swirling Turbulent Flows'," *AIAA Journal,* Vol. 27, No. 9, 1989, p. 1036.

[4]Kim, K. Y., and Chung, M. K., "Reply by Authors to F. B. Gessner and M. A. Leschziner," *AIAA Journal,* Vol. 27, No. 9, 1989, p. 1036.

[5]Rodi, W., "A New Algebraic Relation for Calculating the Reynolds Stresses," *Zeitschrift für Angewandte Mathematik und Mechanik,* Vol. 56, 1976, pp. T219–T221.

[6]Gibson, M. M., and Launder, B. E., "Ground Effects on Pressure Fluctuations in the Atmospheric Boundary Layer," *Journal of Fluid Mechanics,* Vol. 86, Pt. 3, 1978, pp. 491–511.

[7]Gibson, M. M., and Younis, B. A., "Calculation of Swirling Jets with a Reynolds Stress Closure," *Physics of Fluids,* Vol. 29, No. 1, 1986, pp. 38–48.

[8]Gibson, M. M., and Launder, B. E., "On the Calculation of Horizontal Turbulent, Free Shear Flows Under Gravitational Influence," *Journal of Heat Transfer,* Feb. 1976, pp. 81–87.

Reply by Authors to G. C. Cheng

Kwang Yong Kim*
Inha University, Incheon, Korea
and
Myung Kyoon Chung†
Korea Advanced Institute of Science and Technology, Taejon, Korea

THIS is a reply to G. C. Cheng who raised an inconsistency problem between model constants discussed in our reply[1] to previous comments by Gessner[2] and Leschziner[3] on the new eddy viscosity model for computation of swirling turbulent flows.[4]

Our eddy viscosity model [Eq. (4) of Cheng's comment] had been derived from algebraic stress equations[5] by introducing a number of rather crude assumptions [Eq. (5) in Ref. 4] for weakly swirling flows. Therefore, the relations between constants should not be considered as serious ones. They only guide us to determine approximate ranges of the model constants, α and β. Consequently, α and β must be inevitably adjusted in the feasible ranges permitted by the relations. As was shown in Ref. 4, the feasible ranges of α and β are $0.06 \leq \alpha \leq 0.14$ and $0.05 \leq \beta \leq 0.44$ under the local equilibrium condition $P = \epsilon$. Here, $\alpha = 0.09$ was taken to be consistent with the asymptotic case of the eddy viscosity coefficient for $R_i = 0$, and $\beta = 0.25$ was chosen as an average value within the range.

References

[1]Kim, K. Y., and Chung, M. K., "Reply by Authors to F. B. Gessner and M. A. Leschziner," *AIAA Journal,* Vol. 27, No. 9, 1989, p. 1036.

[2]Gessner, P. B., "Comment on 'New Eddy Viscosity Model for Computation of Swirling Turbulent Flows,'" *AIAA Journal,* Vol. 27, No. 9, 1989, pp. 1035–1036.

[3]Leschziner, M. A., "Comment on 'New Eddy Viscosity Model for Computation of Swirling Turbulent Flows,'" *AIAA Journal,* Vol. 27, No. 9, 1989, p. 1036.

[4]Kim, K. Y., and Chung, M. K., "New Eddy Viscosity Model for Computation of Swirling Turbulent Flows," *AIAA Journal,* Vol. 25, No. 7, 1987, pp. 1020–1022.

[5]Kim, K. Y., and Chung, M. K., "Calculation of a Strongly Swirling Turbulent Round Jet with Recirculation by an Algebraic Stress Model," *International Journal of Heat and Fluid Flow,* Vol. 9, No. 1, 1988, pp. 62–68.

Received April 25, 1990; accepted for publication May 26, 1990.

*Associate Professor, Mechanical Engineering, Yonghyun-dong, Nam-ku.

†Professor, Mechanical Engineering, Kusong-dong, Yusong-ku.

Errata

Compatibility Conditions of Structural Mechanics for Finite Element Analysis

S. N. Patnaik and L. Berke
NASA Lewis Research Center, Cleveland, Ohio
and
R. H. Gallagher
Clarkson University, Potsdam, New York

[AIAA Journal 29(5), pp. 820–829 (1991)]

AUTHORS S. N. Patnaik and L. Berke were inadvertently omitted from the title of this article because a correction was improperly applied to the title page. The Journal editorial department accepts full responsibility for this error and extends their apologies to the authors. Please note that their names appeared correctly in the Table of Contents and that they will be indexed correctly in the December 1991 issue of the Journal. Corrected reprints of this article are available from the authors.

Cell Centered and Cell Vertex Multigrid Schemes for the Navier-Stokes Equations

R. C. Swanson
NASA Langley Research Center, Hampton, Virginia 23665
and
R. Radespiel
DLR, Institute for Design Aerodynamics, Braunschweig, Germany

[AIAA Journal 29(5), pp. 697–703 (1991)]

THE following revised table should replace the one published on page 702 of this article:

Table 1 Mesh parameters

Grid	Δy_{min}	Δx_{te}	Δs_{le}	$\Delta x_{x=0.5c}$	SF
193×33	2.25×10^{-5}	5.20×10^{-3}	3.25×10^{-3}	1.39×10^{-2}	1.56
385×65	1.00×10^{-5}	2.46×10^{-3}	1.57×10^{-3}	7.13×10^{-3}	1.25
577×97	6.67×10^{-6}	1.64×10^{-3}	1.04×10^{-3}	4.78×10^{-3}	1.16