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EXPERIENCE WITH k-ε TURBULENCE MODELS FOR HEAT TRANSFER COMPUTATIONS IN ROTATING

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OUTLINE

- Geometry and flow configuration
- Effect of y+ on heat transfer computations
- Standard and Extended k-ε turbulence model results with wall function
- Low-Re model results (the Lam-Bremhorst model without wall function)
- A criterion for flow reversal in a radially rotating square duct
- Summary

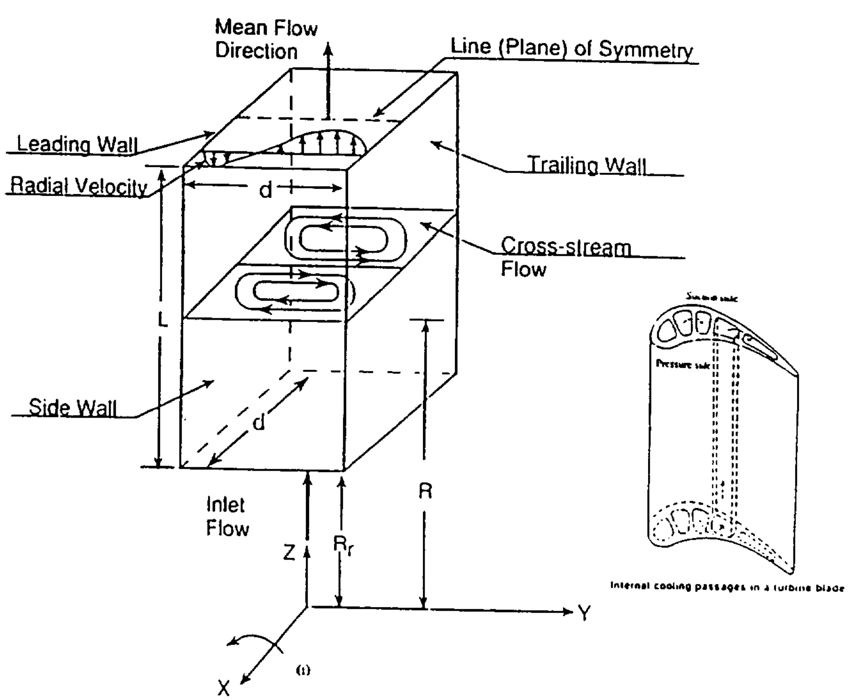

Fig. 1-Illustration of geometry and physics of flow

TWO-EQUATION TURBULENCE MODELS

$$\mu_t = f_\mu C_\mu \rho k^2/\varepsilon$$

$$\frac{D(\rho k)}{Dt} = \frac{\partial}{\partial x_i}\left(\frac{\mu_t}{Pr_k}\frac{\partial k}{\partial x_i}\right) + \rho(G_k - \varepsilon)$$

$$\frac{D(\rho \varepsilon)}{Dt} = \frac{\partial}{\partial x_i}\left(\frac{\mu_t}{Pr_\varepsilon}\frac{\partial \varepsilon}{\partial x_i}\right) + f_1 C_1 \frac{\varepsilon}{k}\rho G_k - f_2 C_2 \rho \frac{\varepsilon^2}{k} + C_3 \rho \frac{G_k^2}{k}$$

where $G_k = \frac{\mu_t}{\rho}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\frac{\partial u_i}{\partial x_j}$; $C_\mu = 0.09$

Standard k-ε model:
$Pr_k = 1.0$, $Pr_\varepsilon \cong 1.3$, $C_1=1.44$, $C_2=1.92$, $C_3=0.0$, $f_1=1.0$, $f_2=1.0$, and $f_\mu=1.0$

Extended k-ε model:
$Pr_k = 0.89$, $Pr_\varepsilon=1.15$, $C_1=1.15$, $C_2=1.9$, $C_3=0.25$, $f_1=1.0$, $f_2=1.0$, and $f_\mu=1.0$

Lam-Bremhorst low-Re model:
$Pr_k = 1.0$, $Pr_\varepsilon \cong 1.3$, $C_1=1.44$, $C_2=1.92$, $C_3=0.0$, $f_1=(1+0.05/f_\mu)^3$, $f_2=1-e^{-R_t^2}$, and $f_\mu=(1-e^{-0.0165R_k})^2\,(1+20.5/R_t)$, where $R_k=k^{1/2}\,y\,\rho/\mu$ and $R_t=k^2\,\rho/\mu\,\varepsilon$

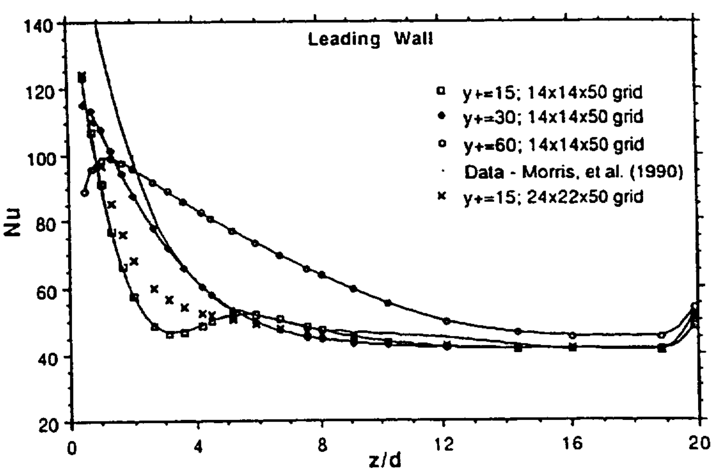

Fig. 2(a)-Effect of y+ and grid size on Nu computation

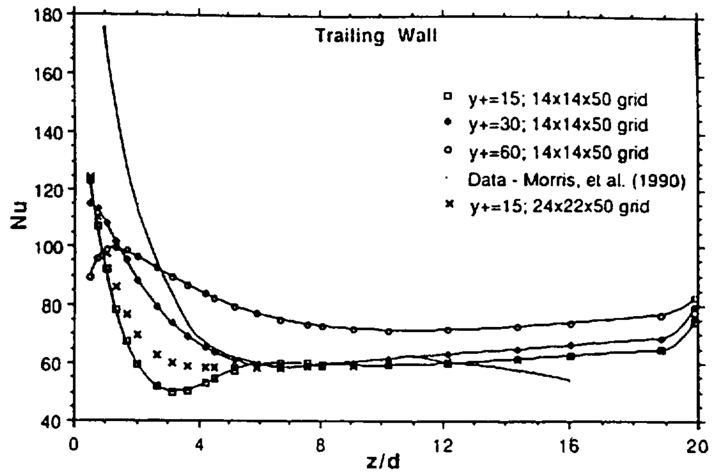

Fig. 2(b)-Effect of y+ and grid size on Nu computation

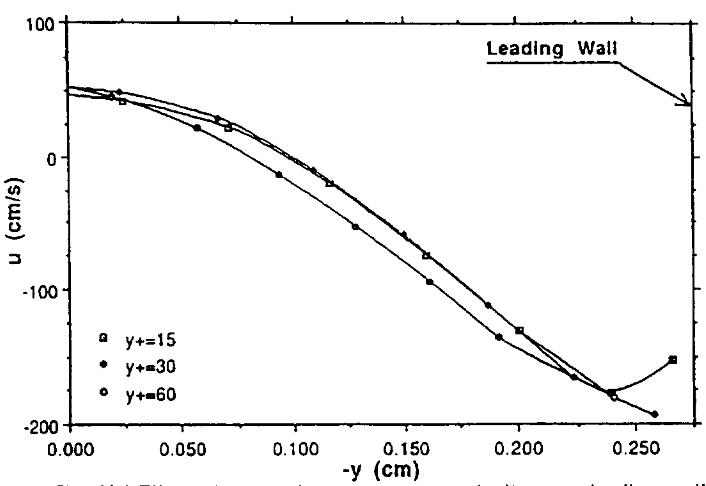

Fig. 2(c)-Effect of y+ on the cross-stream velocity near leading wall

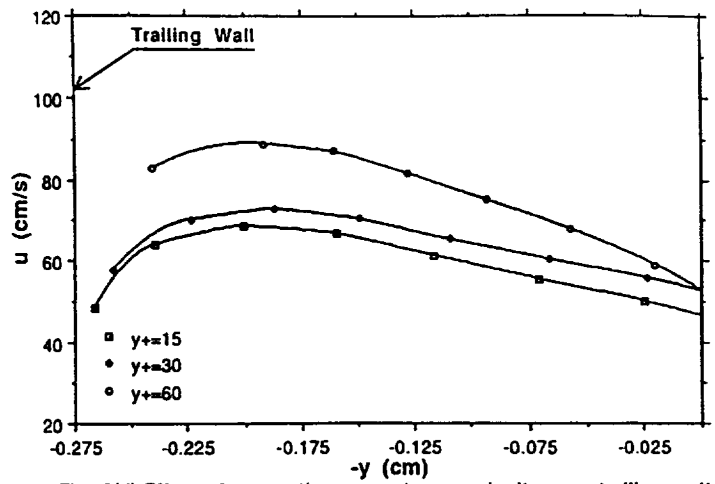

Fig. 2(d)-Effect of y+ on the cross-stream velocity near trailing wall

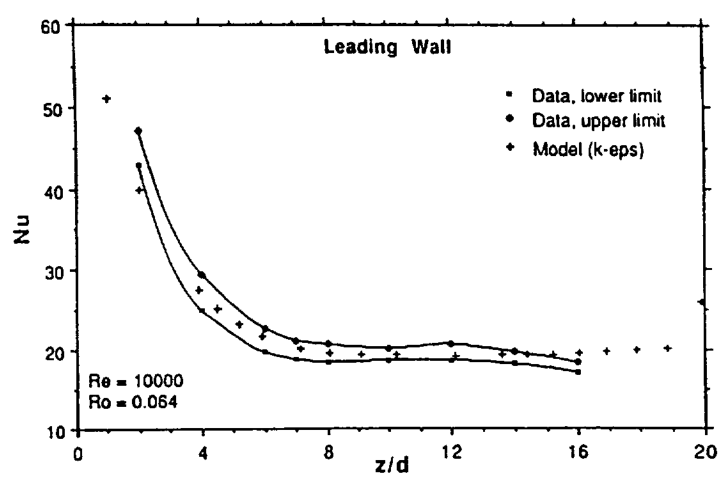

Fig. 3(a)-Comparison of model results with data (Morris & Ghavami-Nasr,1991)

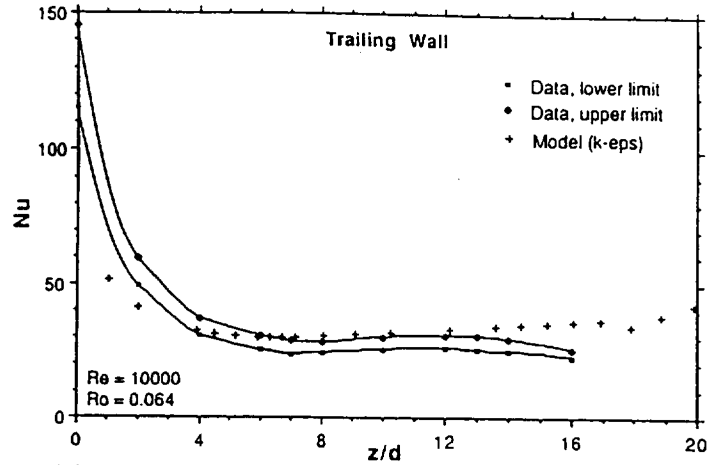

Fig. 3(b)-Comparison of model results with data (Morris & Ghavami-Nasr, 1991)

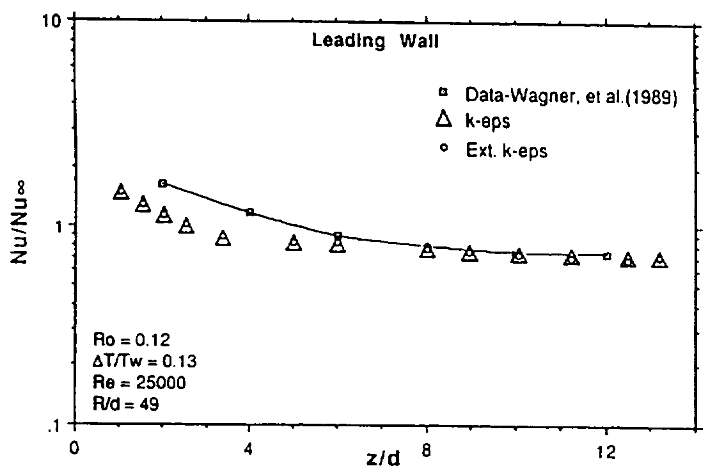

Fig. 4(a)-Comparison of model results with data on leading wall

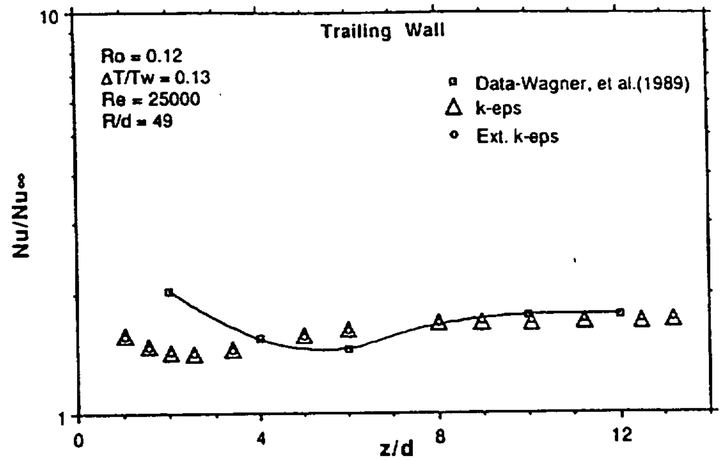

Fig. 4(b)-Comparison of model results with data on trailing wall

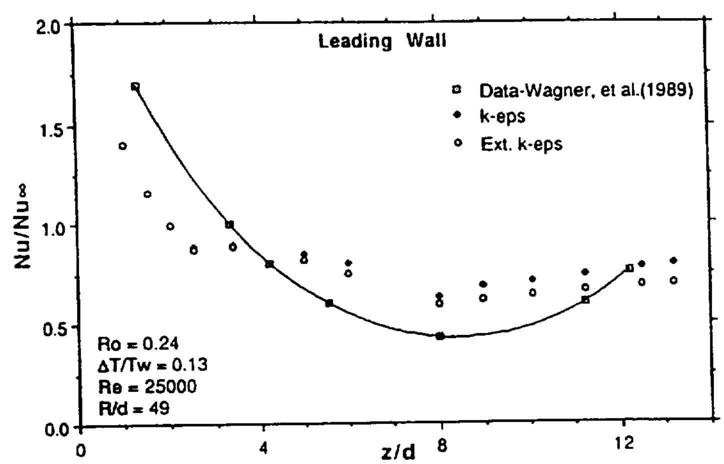

Fig. 4(c)-Comparison of model results with data on leading wall

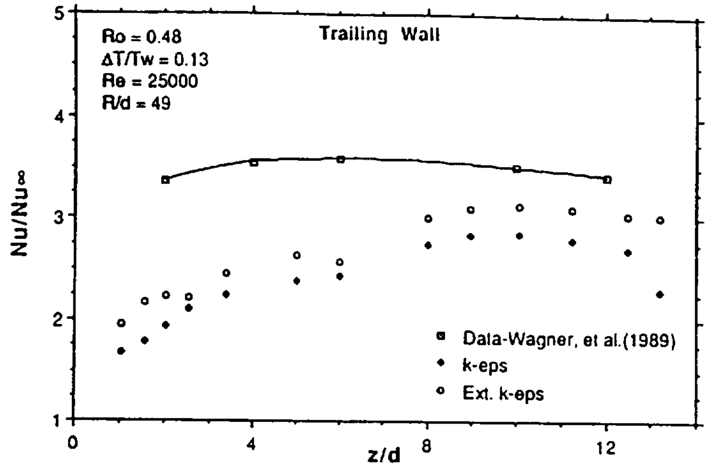

Fig. 4(d)-Comparison of model results with data on trailing wall

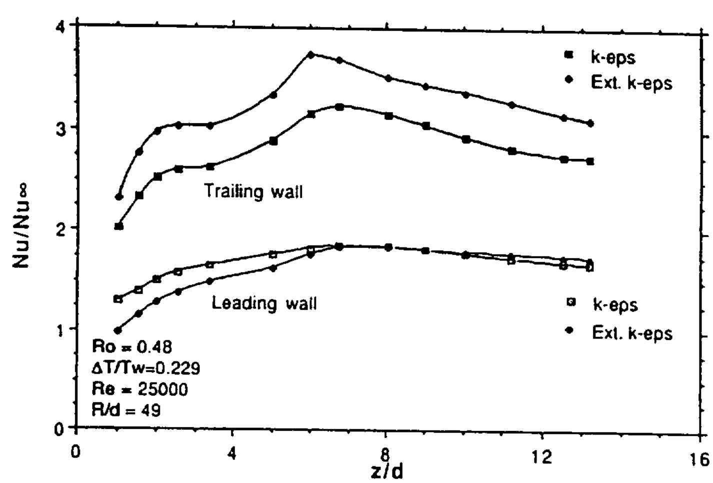

Fig. 5-Comparison of the two model results at high Ro and high density ratio

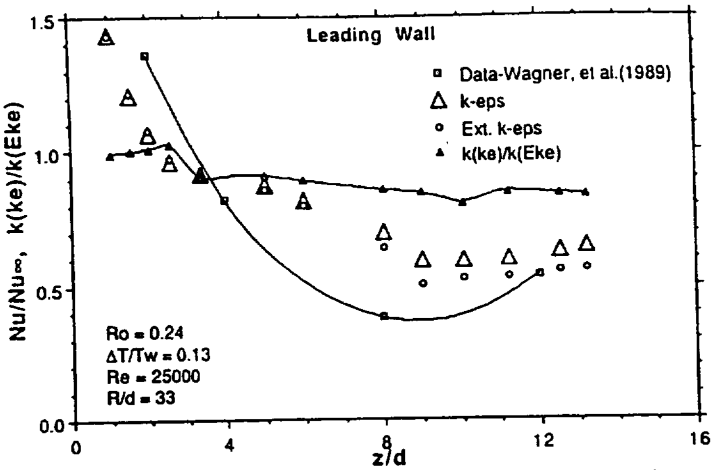

Fig. 6(a)-Plots of Nu-ratio and k-ratio from the two models

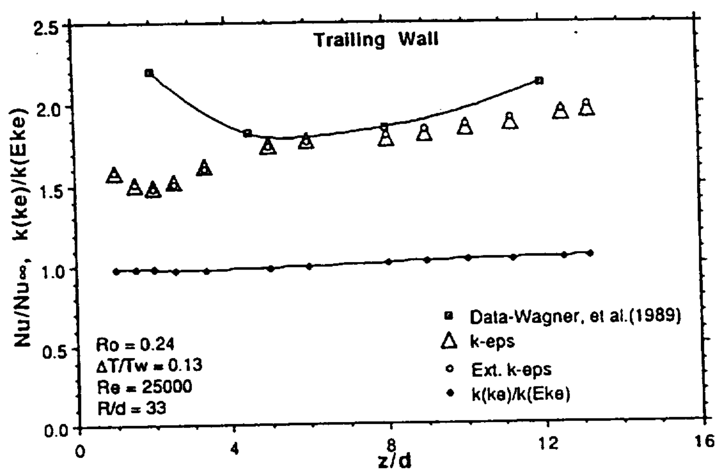

Fig. 6(b)-Plots of Nu-ratio and k-ratio from the two models

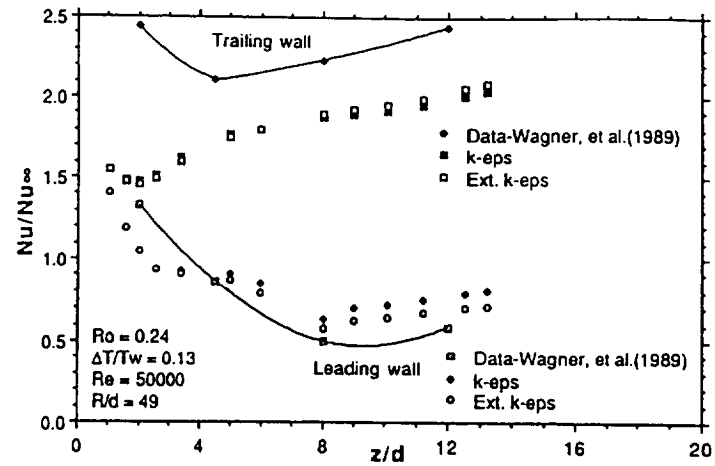

Fig. 7(a)-Comparison on both leading and trailing walls

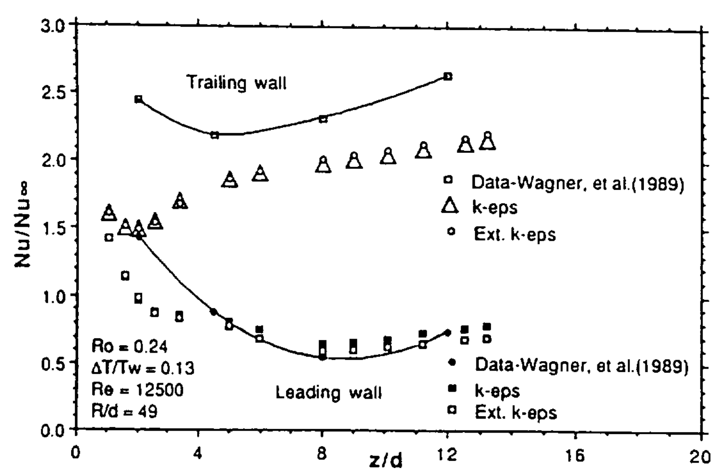

Fig. 7(b)-Comparison on both leading and trailing walls

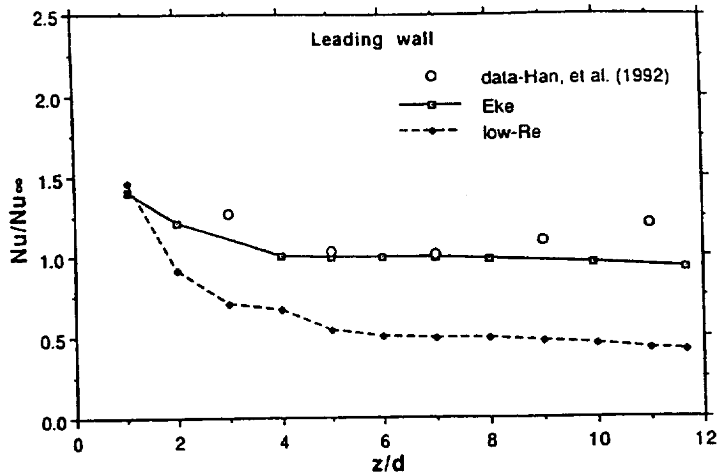

Fig. 8(a)-Comparison of Eke and low-Re results on leading wall (Re=10000,Ro=.088,Case B)

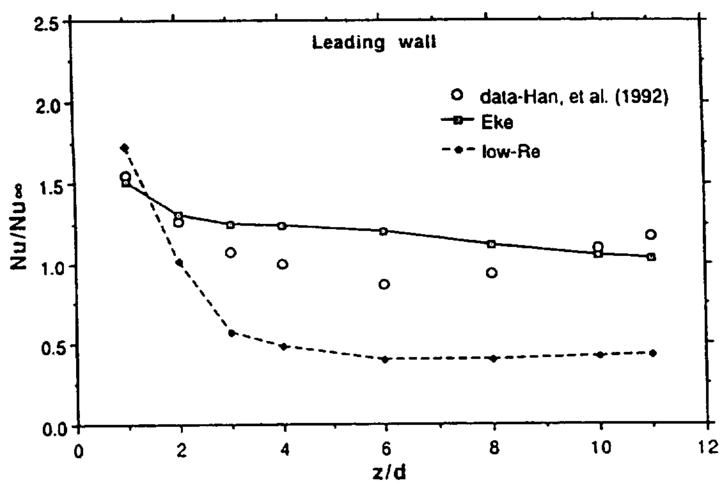

Fig. 8(b)-Comparison of Eke and low-Re results on leading wall (Re=5000,Ro=.176,CaseB)

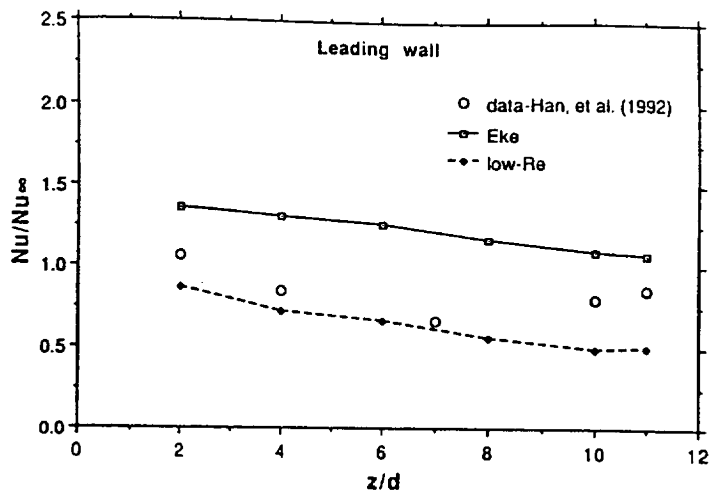

Fig. 8(c)-Comparison of Eke and low-Re results on leading wall (Re=5000,Ro=.176,CaseC)

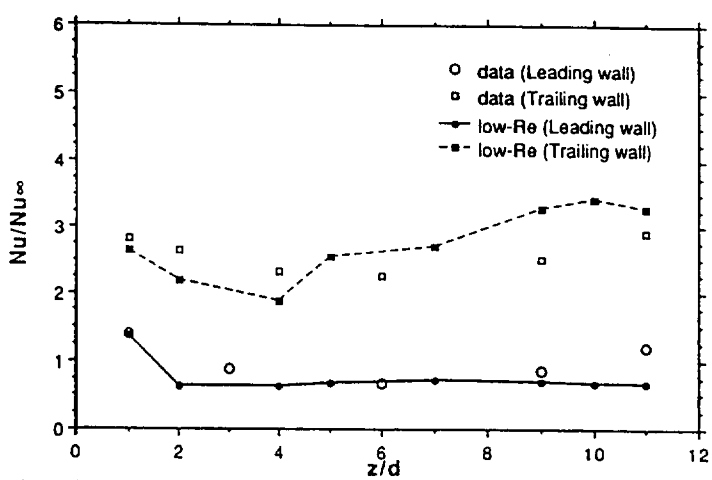

Fig. 8(d)-Comparison of low-Re results with data (Re=2500,Ro=.352,CaseB)

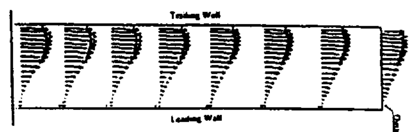

Fig. 9-Velocity vectors in the yz-plane

Table 1 Prediction of Flow Reversal Near the Leading Wall

Ro	ΔT/Tw	R/d	Re	Gr/Re^2	Flow Reversal ?
0.12	0.07	49	25000	0.05	No
	0.13			0.09	No
	0.23			0.16	No
	0.36			0.26	No
	0.48			0.34	Yes
	0.07	196		0.20	No
		300		0.30	Yes
0.24	0.07	33	25000	0.13	No
		49		0.20	No
		196		0.77	Yes
		300		1.18	Yes
	0.13	49		0.36	Yes
	0.16			0.45	Yes
	0.23			0.65	Yes
	0.07		12500	0.20	No
	0.13			0.36	Yes
	0.23			0.65	Yes
0.34	0.13	49	25000	0.73	Yes
	0.16			0.91	Yes
	0.23			1.30	Yes
0.48	0.13	49	25000	1.45	Yes

SUMMARY

1. Near-wall grid size has a significant effect on the heat transfer calculations when the "wall function" treatment is used. Numerical experiment on the data of Morris et al. (1991) suggests that a y+ value in the range of 12 to 42 or so yields more accurate results.

2. The extended k-ε turbulence model, while yielding heat transfer results virtually the same as those of standard k-ε model for low rotation-number flows, provides an improvement over the standard k-ε model by up to 15% or so in heat transfer predictions for high rotation number flows.

3. Wall-function k-ε models predict lower (than data) heat transfer at the trailing wall and higher at the leading wall. The need to properly represent the effect of rotation in the k-ε model equations is realized.

4. The low-Reynolds number model utilizes a large number of cells and the convergence rate is very slow in comparison to the high-Reynolds number model using wall function. It is difficult and expensive to obtain a well converged solution with the low-Re turbulence model.

5. The poor agreement of the low-Re model results with the data makes the low-Re model as an unattractive choice for heat transfer computations in rotating radial outward flow at high Rotation number (> 0.24) and high-Reynolds number (25000).

6. The extended version of high-Reynolds number turbulence model in conjunction with wall function yields satisfactory results for flows with isothermal walls as well as uneven wall temperatures. The agreement is within 5-25% of the data with uneven wall temperatures for flows at Reynolds numbers 10000 or higher.

7. For flows at Reynolds number 5000 or lower, the low-Re model predictions are better, especially for the case of uneven wall temperature conditions.

8. The centrifugal buoyancy may cause a flow reversal near the leading wall depending upon the geometry and flow parameters such as rotation number, temperature ratio, mean radius ratio and Reynolds number. For the square-section channel considered here, a criterion of $Bo=Gr/Re^2$ higher than 0.3 is predicted to cause flow reversal near the leading wall for flows at Reynolds number up to 25000.

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