Department of Aerodynamics
State Polytechnic University,
Polytechnicheskaya 29
195251 St.-Petersburg, RUSSIA
Tel./Fax.: (812)-552-66-21
E-mail: *aerofmf@citadel.stu.neva.ru*

St.-Petersburg
State
Polytechnic
University
(SPSTU)

September 16, 2003

From: Prof. Evgueni M.Smirnov, PhD Student A.M.Levchenya

On performance of the low-Re k-w based SST-model of turbulence implemented in CFX-TASCflow version 2.12.1: analysis of compressibility and heat transfer effects

Introduction

Using CFX-TASCflow version 2.12.1 release, we performed computations of flat-plate compressible boundary layers with the k-ω turbulence models. Instead of the previous report [1], where we used the adiabatic wall boundary condition only, the main issue of the present work is simulation of subsonic boundary layer with a constant temperature of the solid wall. Unfortunately, our results for prediction of the Stanton number using the low-Re SST model are unsatisfactory.

1. Problem Definition

The fluid used is a generic ideal gas (air at STP):

- molecular viscosity $\mu = 1.88 \times 10^{-5}$ kg m^{-1} s^{-1},
- specific heat at constant pressure $C_p = 1003.5$ J kg^{-1} K^{-1},
- specific heat ratio $\gamma = 1.4$,
- temperature recovery factor $r = 0.88$.

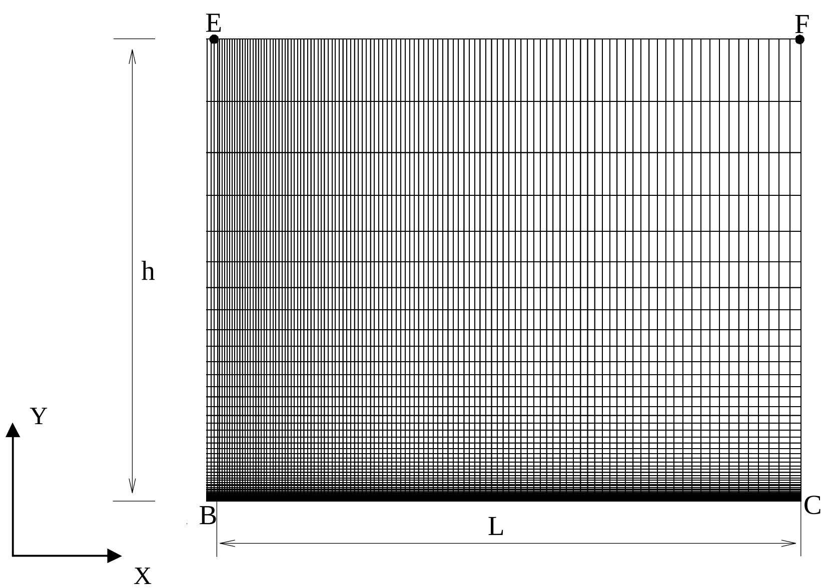

Fig.1. Grid sketch (L=3.048 m, h=0.0762 m)

The boundary conditions are given in Table 1:

Table 1

Region	*Condition*	*Values*
BE	Inflow	Velocity: U = constant value, V=W=0 Temperature: static, constant value Turbulence: intensity (Tu) 0.25%, eddy length scale (L) 1.27×10^{-3} m
CF	Outflow	Pressure: static 91715 Pa
BC	Wall	Stationary, fixed temperature value
EF	Symmetry	-

The grid used in this study is defined by Table 2.

Table 2

Grid dimensions	*Near-wall cell size*	*"Mean" y^+ value*	*Maximum y^+ value*
121x43x3	2.94×10^{-6} m	0.8	1.7

"Mean" y^+ value was estimated at the plate's midpoint (x=1.524 m).

2. Cases descriptions and computation aspects

We performed computations at three values of the temperature ratio for each of two values of the inlet Mach number. The inlet velocity value was defined in order to get needed inlet Mach number. All the six computational cases are described in Table 3.

Table 3

Case	*Inlet Mach number*	*Inlet velocity U_{in}, m/s*	*Temperature ratio (wall to inlet), T_w/T_{in}*	*Inlet temperature, T_{in}, K*	*Wall temperature, T_w, K*
A	0.4	132	1.0	300	300
B	0.4	132	0.95	300	285
C	0.4	209	0.4	750	300
D	0.8	264	1.0	300	300
E	0.8	264	0.95	300	285
F	0.8	418	0.4	750	300

Computations presented below were performed with CFX-TASCflow version 2.12.1 release (solver build 2.12.1-567 for WinXP). Special parameters for computations with the SST model were TWO_EQUATION_MODEL = 3, ZONAL_KW_MODEL = 2, SST_TRANSITION_MODEL=F, FIXED_WALL_DISTANCE_MODEL=F.

3. Results

Figure 1 shows variations of computed skin friction coefficient, C_f, along the plate in comparison with the Van Driest II formula (see [2]) for cases A and C. The distribution obtained for case B is close to case A. It is seen that we have got a good agreement between the calculated and theoretically developed data. Similar results were obtained for cases D to F.

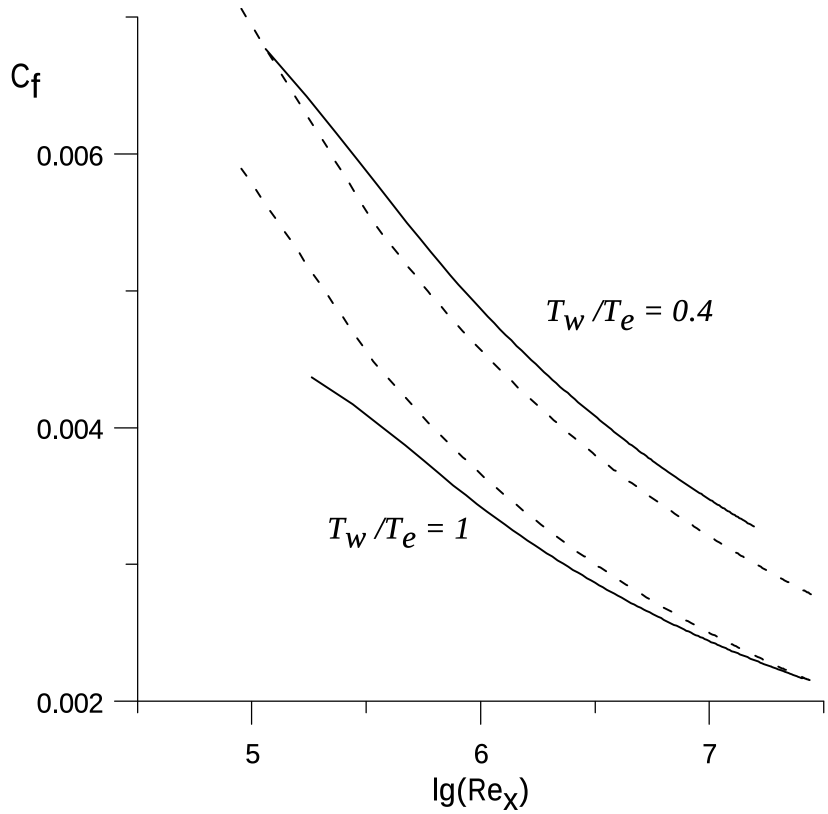

Fig.1. Skin friction distributions for cases A and C (inlet Mach number about 0.4): solid line – computations, dashed line – Van Driest II formula (see [2]).

Figures 2 and 3 are devoted to examination of the Reynolds analogy coefficient. The figures show distributions of the normalized Stanton number. As described in [2], this value should be about 1.16 for turbulent boundary layers. One can see that computations agree well with this value only if the temperature ratio is much less than the unity.

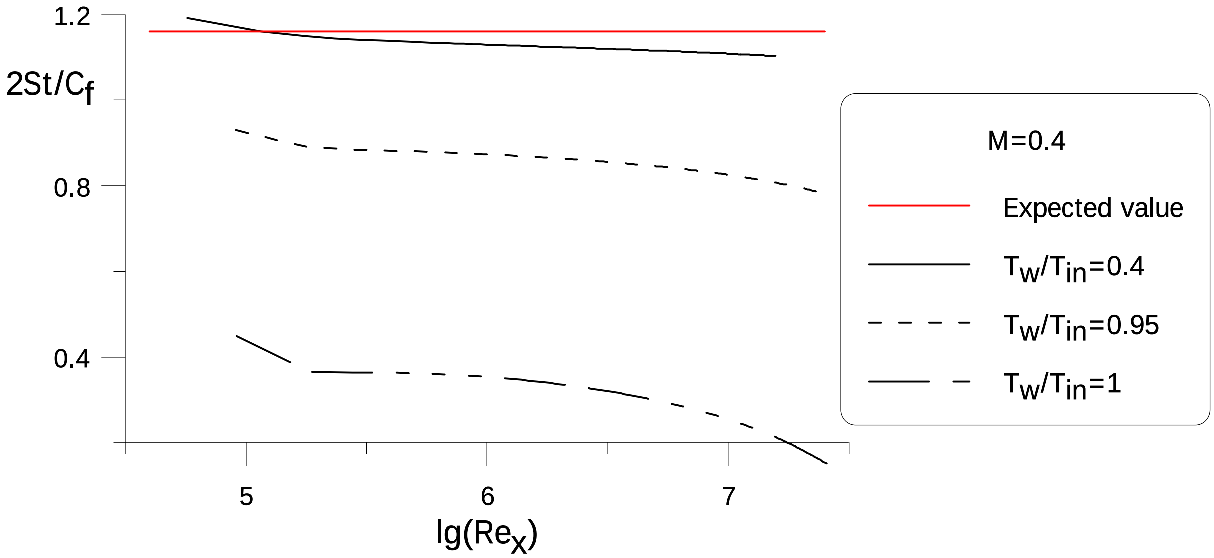

Fig.2. Reynolds analogy coefficient for cases A-C (inlet Mach number about 0.4)

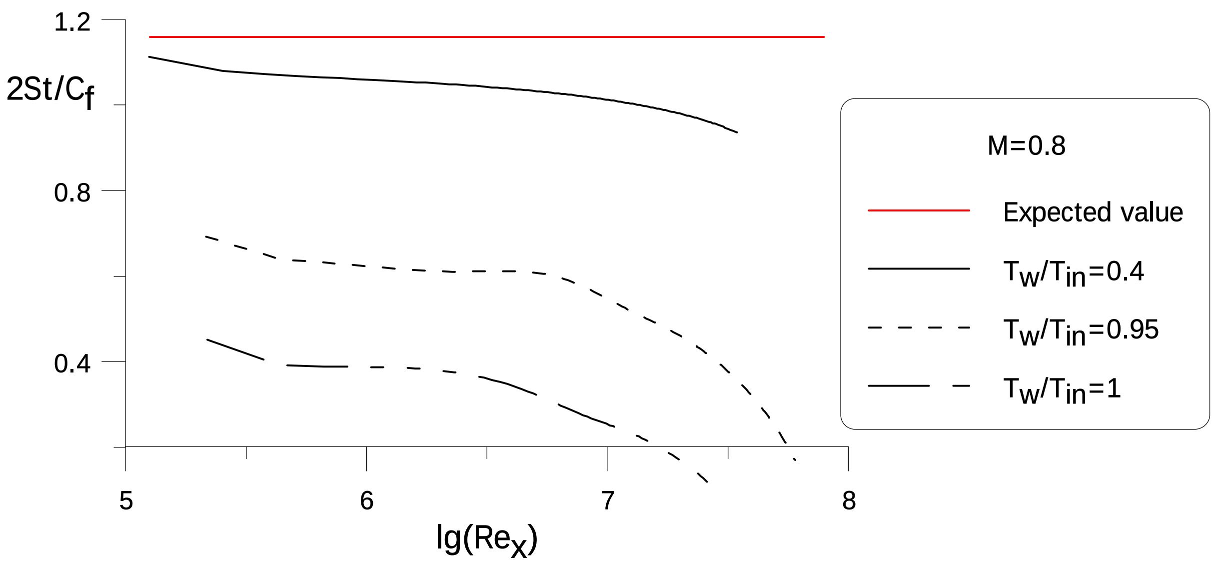

Fig.3. Reynolds analogy coefficient for cases D-F (inlet Mach number about 0.8)

Formulas used for postprocessing are as follows:

$$Re_x = \frac{\rho(x)\cdot U(x)\cdot x}{\mu}; \qquad C_f = \frac{2\cdot \tau_w(x)}{\rho(x)\cdot U(x)^2}; \qquad St = \frac{Q_w(x)}{\rho(x)\cdot U(x)\cdot C_p\left(T_w - T_{in}\left[1+\frac{\gamma-1}{2}rM_{in}^2\right]\right)},$$ where

Re_x - current Reynolds number,
$\rho(x)$, $U(x)$ - free-stream flow density and velocity (along line EF),
$Q_w(x)$, $\tau_w(x)$ - wall heat flux and wall shear stress (along line BC).

4. Questions

1) The Reynolds analogy coefficient computed with the low-Re SST model for subsonic boundary layers is unacceptably underpredicted if the temperature ratio is close to the unity.
2) What is the sense of the undocumented solver parameter HEAT_FLUX_REGRESSION_210? Is this parameter dedicated to heat flux computations?

References

1. Levchenya A.M., Smirnov E.M. (2003). On performance of the low-Re k-ω based SST-model of turbulence implemented in CFX-TASCflow version 2.12.1. Personal communication.
2. Cebeci T., and Bradshaw P. (1984) Physical and computational aspects of convective heat transfer. Springer-Verlag.