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TEST CASES FOR NPARC

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1 Objective

In order to insure efficient and accurate utilization of the NPARC2D code[1], test computations for a supersonic adiabatic turbulent boundary layer have been performed. The computations have been compared with results obtained using the EDDYBL code of Wilcox [2] which employs the same turbulence model.

2 Flow conditions

The test case is a flat plate parallel to the x-axis. We have also performed a computation for the flat plate having an angle (*e.g.*, half radian) to the x-axis and obtained similar results, thereby the accuracy of the implementation of the coordinate transformation derivatives $\partial\xi_1/\partial y and \partial\xi_2/\partial x$ [1].

2.1 Upstream Profile

The upstream profile for the NPARC2D computation was generated using the EDDYBL program with the same freestream condations presented in Table 1

Total pressure	P_{t_∞}	$2.3122 \times 10^4 Nt/m^2$
Total temperature	T_{t_∞}	$260^\circ K$
Mach number	M_∞	2.0
Pressure	P_∞	$2.945 \times 10^3 Nt/m^2$
Temperature	T_∞	$144.4^\circ K$
Density	ρ_∞	$7.128 \times 10^2 kg/m^3$
Sound speed	a_∞	$240.9 m/s$
Velocity	U_∞	$461.7 m/s$
Viscosity	μ_∞	$9.919 \times 10^{-6} Nt - s/m^2$
Reynolds number	R_{l_∞}	$3.462 \times 10^6 m^{-1}$
Temperature at Wall	T_w	$248^\circ K$

Table 1: Freestream condations for NPARC calculation

and SSTOP=1.33m. We also performed the compution with SSTOP=1.34 in order to determine the vertical velocity from the continuity equation. The freestream conditions are described in Table 1. The initial conditions for the EDDYBL program are shown in Table 2. The standard turbulence model constants are used [2], and the Chien low Reynolds number model is employed.

Note: $T_w = T_{aw} = (1 + \frac{(\gamma-1)}{2} Pr_t M_\infty^2) T_\infty = 248K$
but at end of BL calculation, $T_w = 238.57 \circ K$

2.2 Grid

The detail of the grid are presented in Table 3. Two separate grids were utilized to enable examination of the truncation error effects.

For case 1, we use same Grid as Wilcox's BL code, adding points to reach $KMAX = 131$ with stretching facto 1.07 applied to added ponits. This yields $y_\infty = 0.54246m$.

Skin coefficient	C_f	3.0×10^{-3}
Shape factor	H	1.8
Reynolds number	R_{l_θ}	$1500m^{-1}$
Momentum thickness	θ	$4.33 \times 10^{-4}m$
Boundary-layer thickness	$\delta = 12 \times \theta$	$5.2 \times 10^{-3}m$
Start position	x_{start}	$0.2889m$
Reynolds number at x_{start}	$R_{l_{x_{start}}}$	$10^6 m^{-1}$
Max value of arclength	SSTOP	1.33m
	KODWAL	2
heat flux specified		0
Initial streamwise stepsize	DS	3.2×10^{-3}

Table 2: Initial condition for EDDYBL code

Characteristic length		$\Delta x_r = \delta_0$	$1.9255 \times 10^{-2}m$
Grid spacing in X		$\Delta x = \Delta x^* / x_r$	1.00
Case 1	Maximum index number in X	JMAX	50
	Maximum index number in Y	KMAX	131
Case 2	Maximum index number in X	JMAX	99
	Maximum index number in Y	KMAX	261

Table 3: Grid spacing in X and Y

Density	$\rho = \rho_\infty$	$7.128 \times 10^{-2} kg/m^3$
Temperature	$T_r = T_\infty$	$144.4^\circ K$
Sound speed	$a_r = a_\infty$	$240.87 m/s$
Viscosity	$\mu_r = \mu_\infty$	$9.919 \times 10^{-6} Nt - s/m^2$
Cartesian coordinates	$x_r = \delta_0$	1.9255×10^{-2}
Reynolds number	$R_l = \rho_r A_r x_r / \mu_r$	$3.333 \times 10^4 m^{-1}$
Prandtl number	P_r	0.72
	$\beta_r = a_r^2 / c_{p_r} T_r = R/c_v = \gamma - 1$	0.4
Gas Constant	R	$287 J/kg^\circ K$

Table 4: Reference value for NPARC2D

Case	Running time per iteration	Total iterations
Case 1	0.7272 s	20000
Case 2	4.7111 s	4000

Table 5: Running time

For Case 2, we use linear interpolation to get the initial profile.

2.3 Reference Value and input parameters for NPARC

The NAMELIST parameters for NPARC2D are shown in Figure 1. The reference values are presented in Table 4.

2.4 Running time

Using HP9000/Model730, the running time is presented in Table 5.

Note, for 99x261 case, the restart file is created from the result of 50x131

```
 ****************************************************
 K-PATCHES   MINIMUM        MAXIMUM
             J    K   NPARC 1.2a K
     1        2    2        49  130
                    NPARC ALLIANCE
                NASA LEWIS & USAF AEDC

                        JULY 1994

 ****************************************************

0     NAMELIST INPUTS:

                                      IAXISY  =     0
     PREF    =   6.168000E+01         NBLOCK  =     1
     TREFR   =   2.599200E+02         NMAX    =  6000
     VRAT    =  -6.666700E-01         NC      =  5000
     TSUTH   =   1.986000E+02         NSPRT   =    50
     RE      =   3.333000E+04         NP      =  6001
     PR      =   7.200000E-01         IFXPRT  =     0
                                      IFXPLT  =     0
     DTCAP   =   5.000000E-01         L2PLOT  =     0
     PCQMAX  =   1.000000E+01         IPLOT   =     0
     SPLEND  =   5.000000E-01         NSKIP   =     4
     SMOO    =    .000000E+00         MBORD   =     1
     STOPL2  =   1.000000E-11         NUMDT   =     0
     STOPTR  =   1.000000E+02         IVARDT  =     2
     ALPHA   =    .000000E+00         ISOLVE  =     1
                                      IRHS    =     1
     XMACH   =   2.000000E+00         ISPECT  =     1
                                      IFILTR  =     2
     GAMMA   =   1.400000E+00         IMASS   =     1
     DIS2    =    .000000E+00         NOBORT  =     0
     DIS4    =    .000000E+00         LREST   =     0
                                      LREC45  =     0


 THE ORDER OF BLOCK PROCESSING FOLLOWS
 1


0     NAMELIST TURBIN:

     PRT     =   9.000000E-01         IMUTUR  =     2
     ORDER   =   1.000000E+00         NTURB   = -1000
     TUIN1   =   1.000000E-02         NRLX    =     1
     TUIN2   =   2.000000E-02         ITCOMP  =     0
     TUIN3   =   1.000000E-01         IFMAX   =     3
     TMUIN1  =   1.000000E+00
     TMUIN2  =   1.000000E+01
     TMUIN3  =   1.000000E-01
     TMUMAX  =   1.000000E+04
     UREFKE  =   1.000000E+00

1FOR BLOCK  1
 JMAX =  50  KMAX =  131
 NM =  131    NIP =  131    JKLM =  6550

0     NAMELIST BLOCK FOR BLOCK  1
     GAMMA   =   1.400000E+00         INVISC  =     1  1
     COFMIX  =   9.000000E-02         LAMIN   =     0  1
     DTBLK   =    .000000E+00         NPSEG   =     1
     DIS2    =    .000000E+00         NBCSEG  =     0
     DIS4    =    .000000E+00
0     NAMELIST PRTSEG FOR BLOCK  1
                                     JKLPI              IPORD
              JA   JB   JS        KA   KB   KS         J    K
       1       1   50    4         1  131    1         2    1
0     NAMELIST BOUNDS FOR BLOCK  1
0    JSEG  JLINE  JKLOW JKHIGH  JTYPE  INTERJ  JSIGN   PRESSJ         TEMPJ         JTYPE
       1      1      1    131    -10             1                                FIXED
       2     50      1    131      3            -1                                EXTRAPOLATION
0    KSEG  KLINE  KJLOW KJHIGH  KTYPE  INTERK  KSIGN   PRESSK         TEMPK         KTYPE
       1      1      2     49     60             1                                NO-SLIP ADIABATIC
  THE TURBULENCE MODEL WILL END THE
  INNER WALL MODEL SHEAR LAYER SEARCH AT GRID LINE  132
       2    131      2     49      3            -1                                EXTRAPOLATION
1 GRID PATCHES FOR BLOCK  1

 J-PATCHES   MINIMUM        MAXIMUM
             J    K         J    K
     1        2    2        49  130
```

Figure 1: Parameters for NPARC

case by doing linear interpolation.

3 Result

The L2 norm residual for the Navier-Stokes equations is used as the criteria of convergence. It's behavior is presented in Figure 11.

The truncation error effects are insignificant and the computed solutions for Case 1 and Case 2 are compared with results obtained using EDDYBL code of Wilcox [2] which employs the same turbulence model. For velocity U and static temperature T, the agreement is excellent (Figures 2 to 5).

For turbulence kinetic energy k and turbulence kinetic energy dissipation rate ε, the agreement is good (Figures 6 to Figure 9).

For skin coefficient C_f, we have excellent agreement(Figure 10). Note,

$$C_f = \frac{\mu_w^* \partial U^*/\partial y|w^*}{\frac{1}{2}\rho_\infty^* U_\infty^{*2}} = \frac{1}{R_e}\frac{\mu_w \partial U/\partial y|w}{\frac{1}{2}\rho_\infty U_\infty^2}$$

where $\partial U/\partial y|w$ is approximated by a first order forward difference at the wall.

References

[1] G. K. Cooper and J. R. Sirbaugh, "PARC Code: Theory and Usage," Tech. Rep. AEDC TR 89-15, Arnold Engineering Development Center, December 1989.

[2] D. C. Wilcox, *Turbulence Modeling for CFD.* DCW Industries, Inc., 1993.

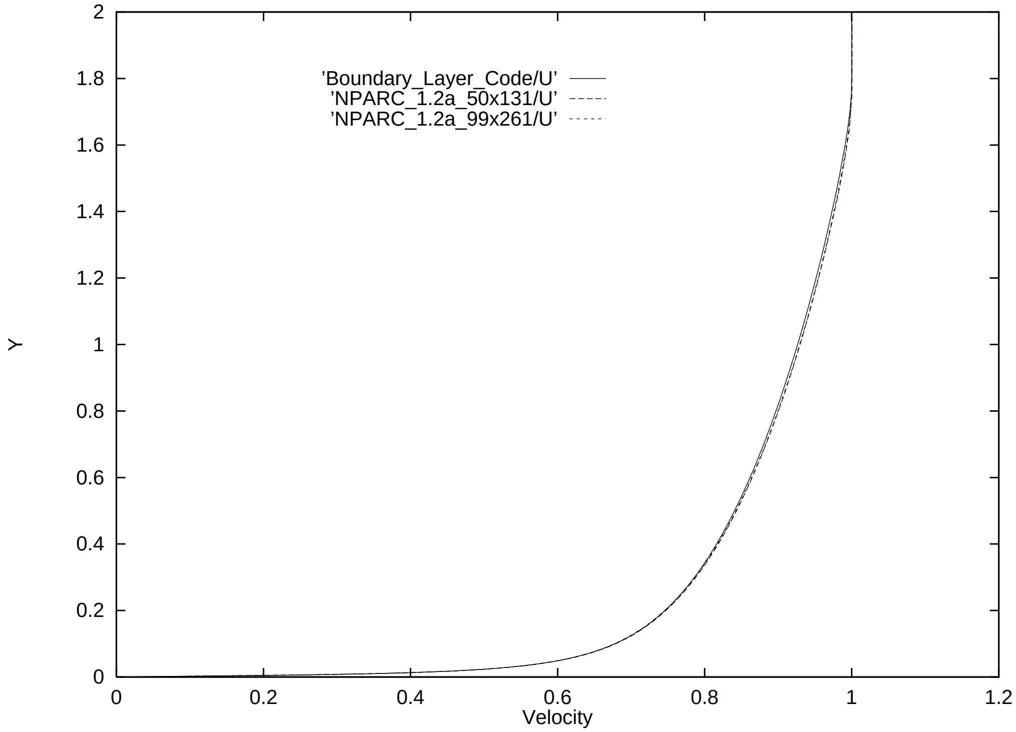

Figure 2: Velocity

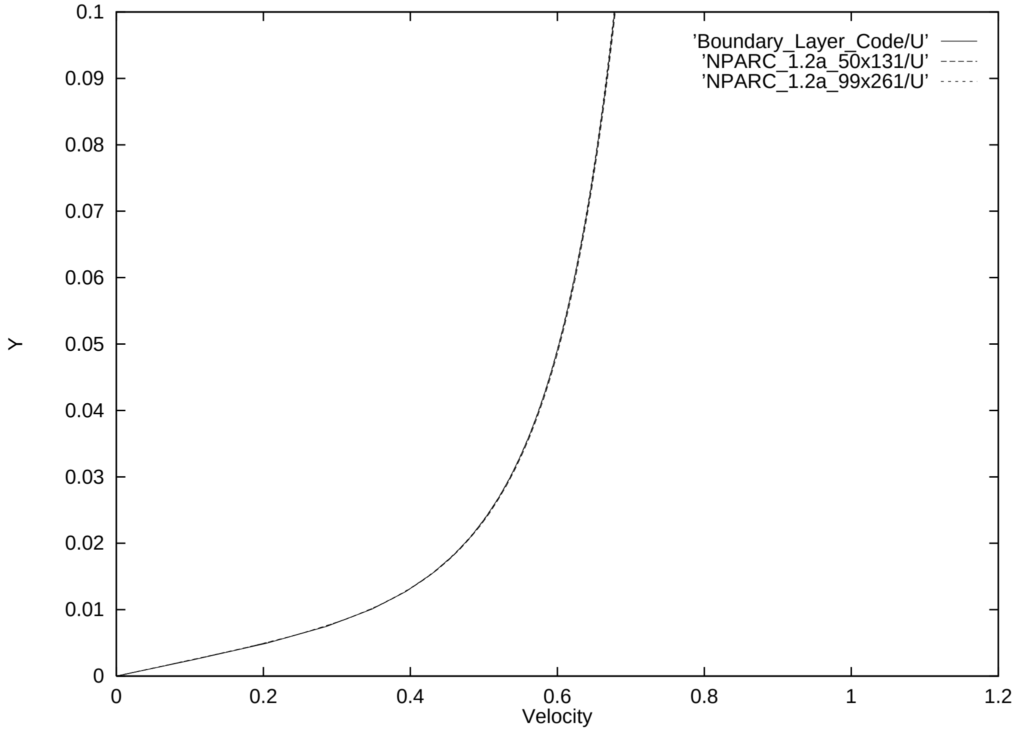

Figure 3: Velocity

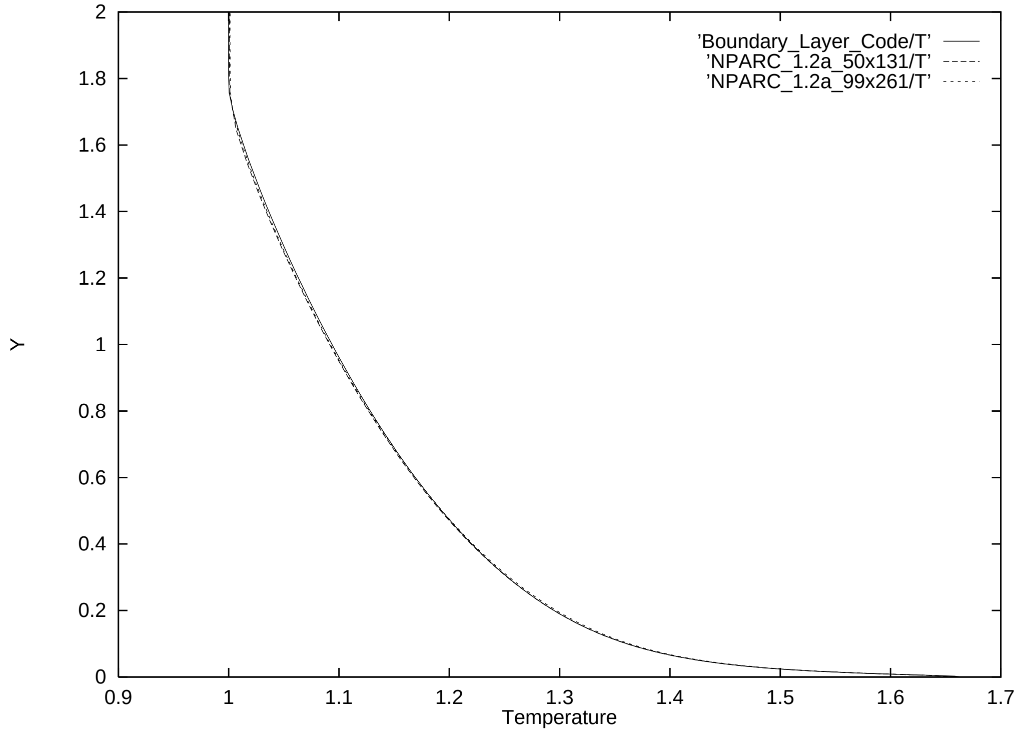

Figure 4: Static temperature

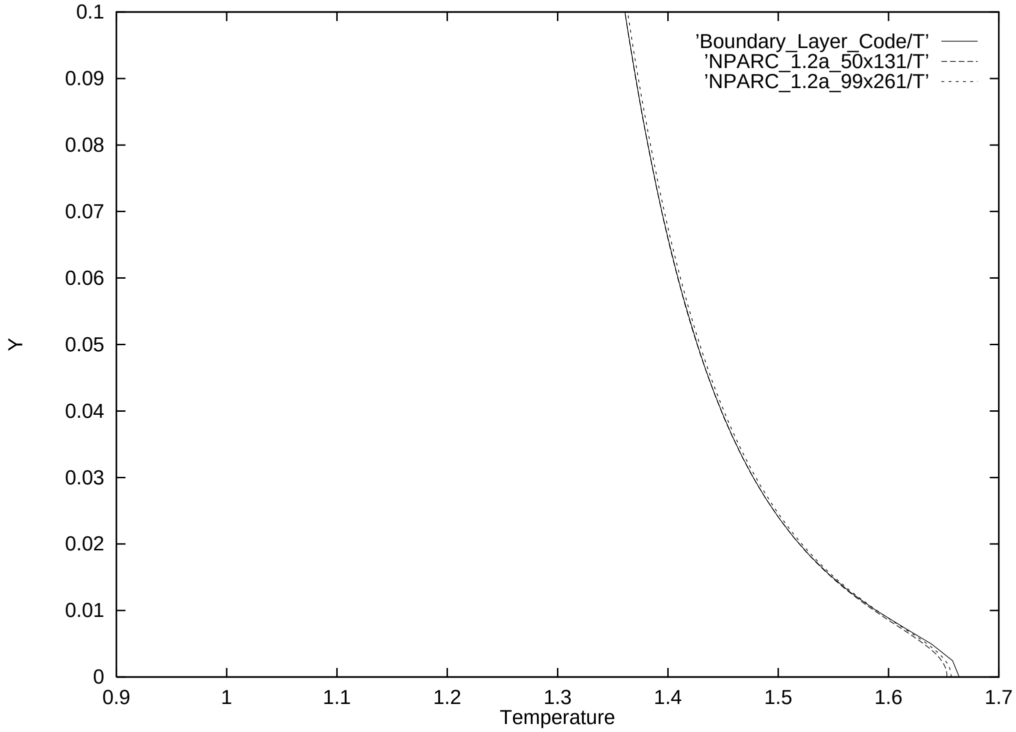

Figure 5: Static temperature

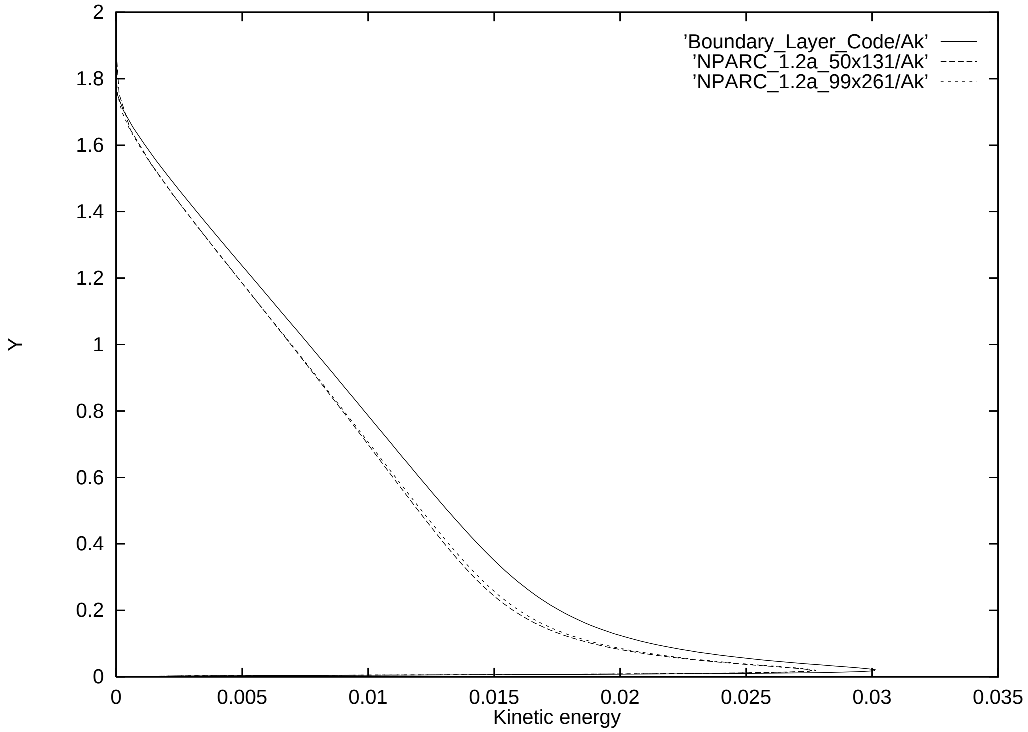

Figure 6: Turbulence kinetic energy

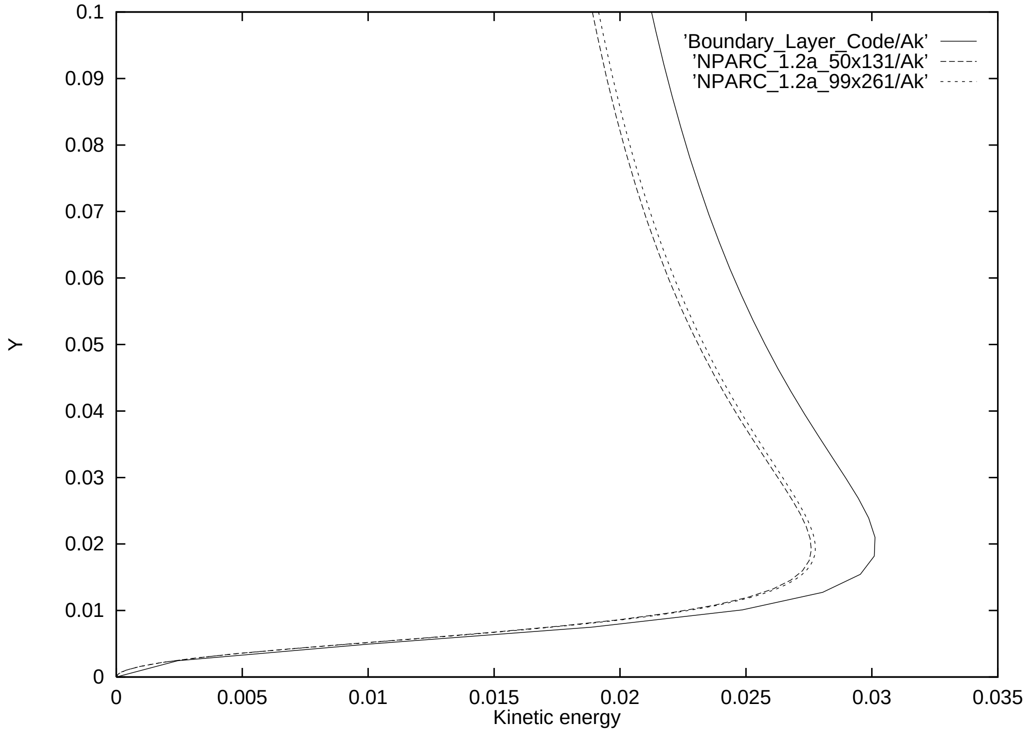

Figure 7: Turbulence kinetic energy

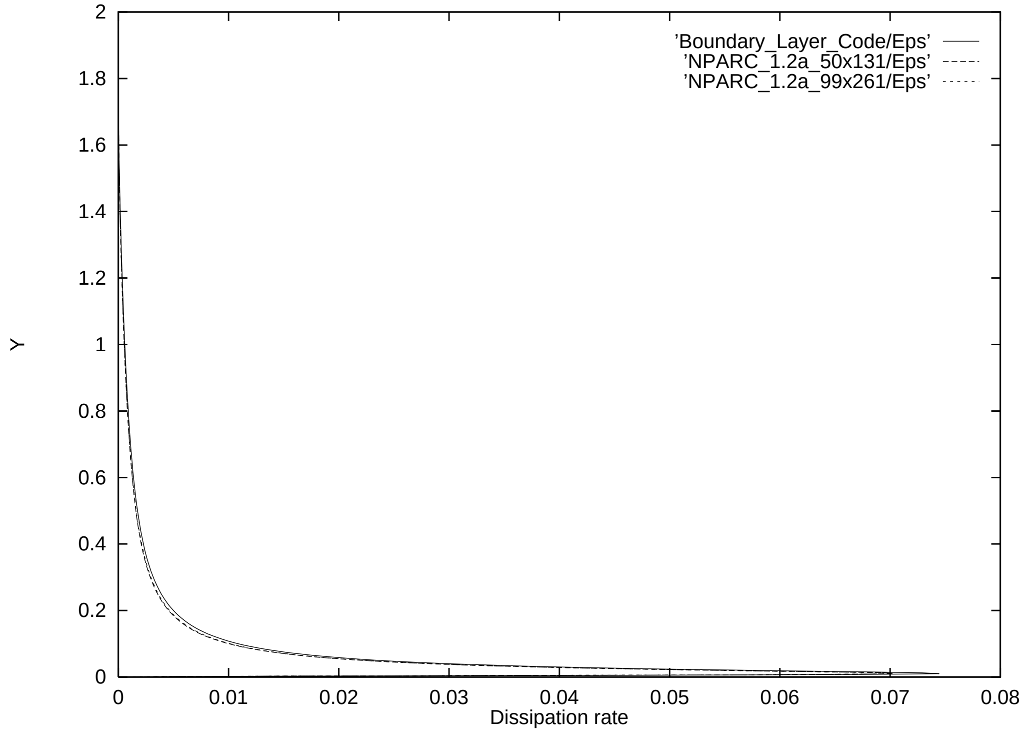

Figure 8: Turbulence kenetic energy dissipation rate ε

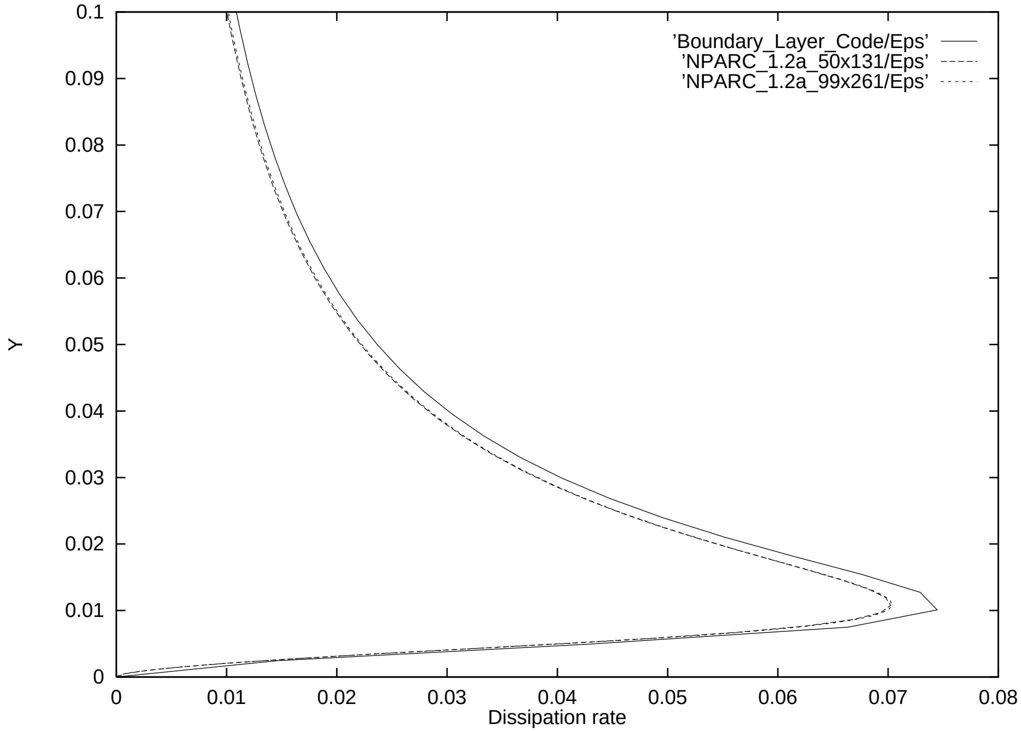

Figure 9: Turbulence kenetic energy dissipation rate ε

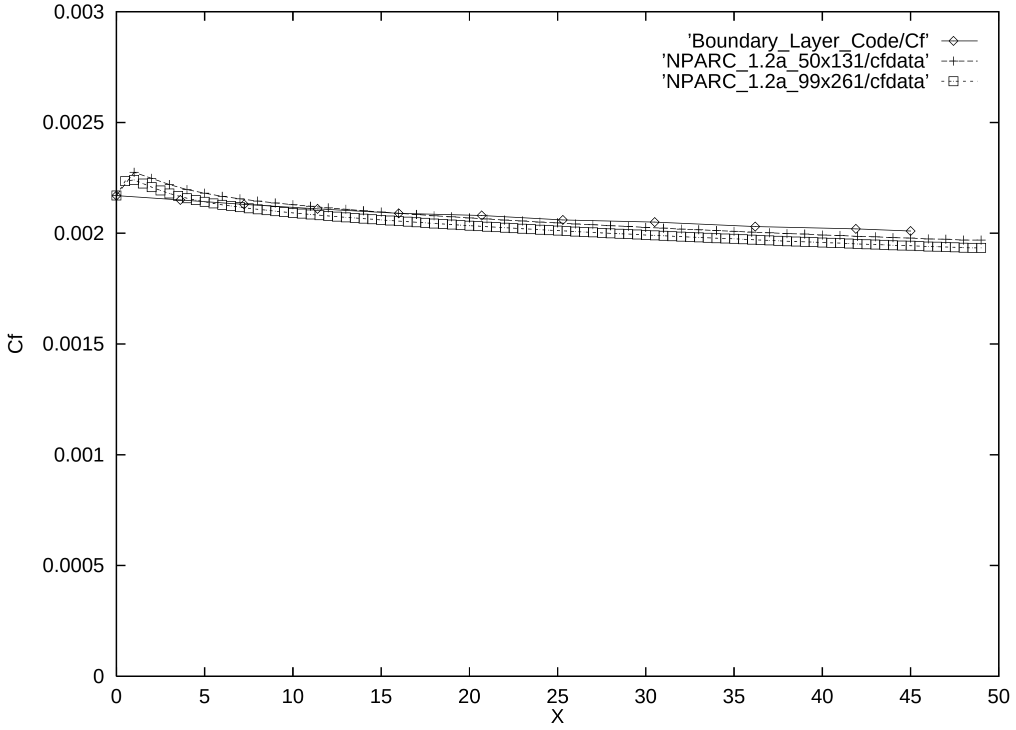

Figure 10: Skin Coefficient C_f

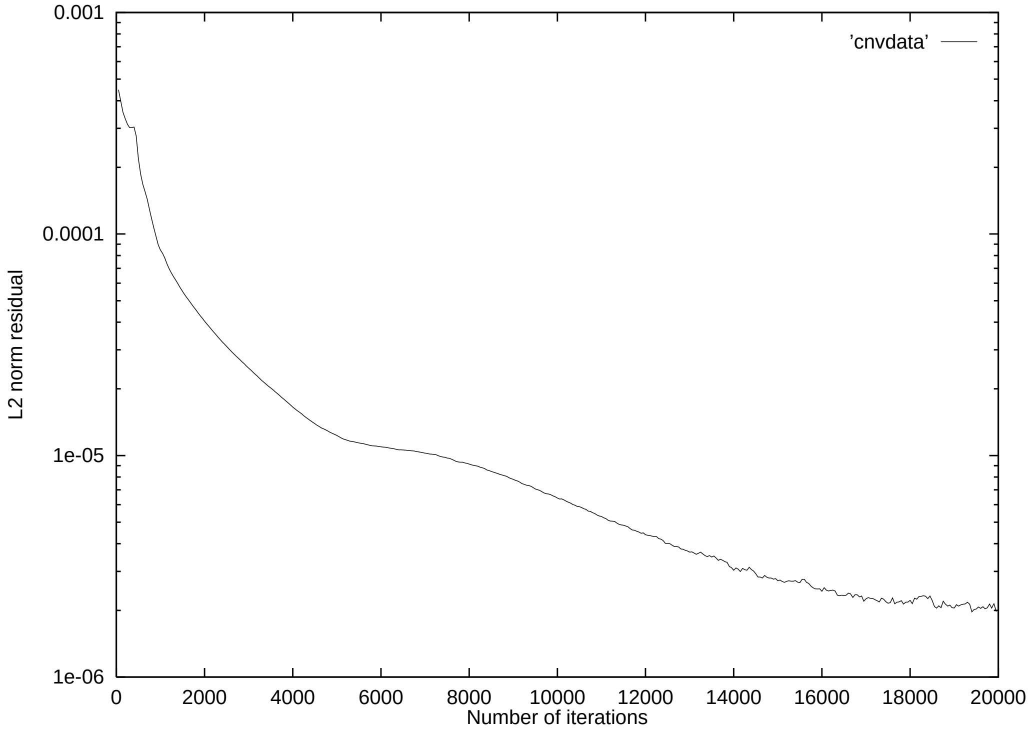

Figure 11: L2 norm residue