Program EDDYBL

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Contents

1 Procedure for Running EDDYBL Source Code

1.1 eddybl_start

The Program **eddybl_start** will prepare the profiles for the main Program **eddybl**.

- Input Files. Program **eddybl_start** read the input file (**eddybl_start.inp**) from the terminal which has the details for all the parameters. When running Program **eddybl_start**, it reads the following files **"Edge_WallProperty.dat "** and **"InitialFinalSlop.dat "** if the option **ireadWallProp** = 1.

- Output Files. Program **eddybl_start** can generate the following files. 1. **eddybl.dat**: the input file for Program **EDDYBL**. 2. **Profile_inflow.dat**: the initial profile for starting the computation. 3. **table.dat**: the nondimensional Edge/Wall properties for starting the computation. 4. **Check_eddybl_start.prt**: information for checking the input value. 5. **Check_Profile_inflow.dat**: the plotting data for checking the initial profile.

1.2 eddybl

The main Program **EDDYBL** will read the files generated by the Program **eddybl_start**.

- Output Files. Program **EDDYBL** generates the following files. 1. **Stat_eddybl.dat**: the profiles for starting the DNS computation, which has the variables z, $\frac{z}{\delta}$, z^+, $\overline{u}$, $\overline{v}$, $\overline{w}$, $\overline{p}$, $\overline{T}$, eddy viscosity μ_T and turbulence kinetic energy k. 2. **profil2c.dat**: used to initial Program **EDDY2C**. 3. **Check_eddybl.prt**: a comprehensive print file for the results of the computation. It has all the integral parameters at each step and dimensionless boundary-layer profiles at the final step. 4. **Int_eddybl.dat**: plotting data at each streamwise locations with Δx defined in the file **eddybl_start.inp**. Including variables are x, Re_θ, Cf_e, δ, δ^*, θ, τ_w, u_τ, z_τ, Re_τ. 5. **Profile_output.dat**: for restarting a run if desired.

1.3 Restart

- 1. Set **irestart=1** and give the inflow profile file name for the restart problem in the input file **eddybl_start.inp**. 2. Change the parameter **xend** in the input file **eddybl_start.inp** and run Program **eddybl_start**.

1.4 Format of the file

The content of the **Edge_WallProperty.dat** is list below.
Warning: If **xbeg** is less than **xloc_min**, the Edge/Wall properties in the region (**xbeg**$\leq$x$\leq$**xloc_min**) keep the same with the properties at the location **xloc_min**. In the same way, if **xend** is great than **xloc_max**, the Edge/Wall properties in the region (**xloc_max**$\leq$x$\leq$**xend**) keep the same with the properties at the location **xloc_max**.

```
xloc(m) pe(pa) tw(k) qw rvwald  rmi(m)   z(m)  zcurv(1/m)
0.      673.6  300   0. 0.      0.3048   0.     0.
6.096   673.6  300   0. 0.      0.3048   6.096  0.

#################### Nothing is read below ##################################
Edge/wall properties corresponding to num_profile = 2 for the current example
      xoc(m)     pe(pa)  tw(k)    qw  rvwald  rmi(m)     z(m)    zcurv(1/m)
      0.        673.6   300      0.   0.     0.3048     0.       0.
      6.096     673.6   300      0.   0.     0.3048     6.096    0.

              xloc: arclength along the body
     xloc =     0 m for the minimum streamwise location for the computation
     xloc = 6.096 m for the maximum streamwise location for the computation
                pe: pressure at the boundary-layer edge
                Tw: surface temperature
 qw(watts/(m^3sec)): surface heat flux
rvwald(kg/(m^2sec)): surface mass transfer rate
               rmi: boundary radius
                 z: axial distance along the body
             zcurv: curvature of the body. This is the reciprocal of
                    the radius of curvature.
```

The content of the **InitialFinalSlop.dat** is list below.

```
dpds    dTwds  dqwds  dmds  drds  dzds  dKds
0.       0.     0.     0.     0.   1.    0.
0.       0.     0.     0.     0.   1.    0.



#################### Nothing is read below ##################################
```

The first line is the initial slop.
The second line is the final slop.

```
         dpds(N/m^3): value of the streamwise pressure gradient.
          dTwds(k/m): value of the streamwise surface-temperature gradient.
 dqwds(Watts/m^3sec): value of the streamwise surface heat-flux gradient.
   dmds(kg/(m^3sec)): value of the streamwise mass-flux gradient.
 drds(Dimensionless): value of the streamwise body-radius gradient.
 dzds(Dimensionless): value of the streamwise axial-distance gradient.
         dKds(1/m^2): value of the streamwise curvture gradient.
```

2 EDDYBL Results

Figure 1 shows the comparison results from three turbulence models. The reference length δ_{ref} is chosen at the station where $Re_\tau = 2000$.

All distributions of the variables have almost the same slop in the downstream of the domain. The reason for the jump using the Stress-omega model is not clear now.

Figure 2 shows the restart case. The computation from Box1 to Box2 is continuous.

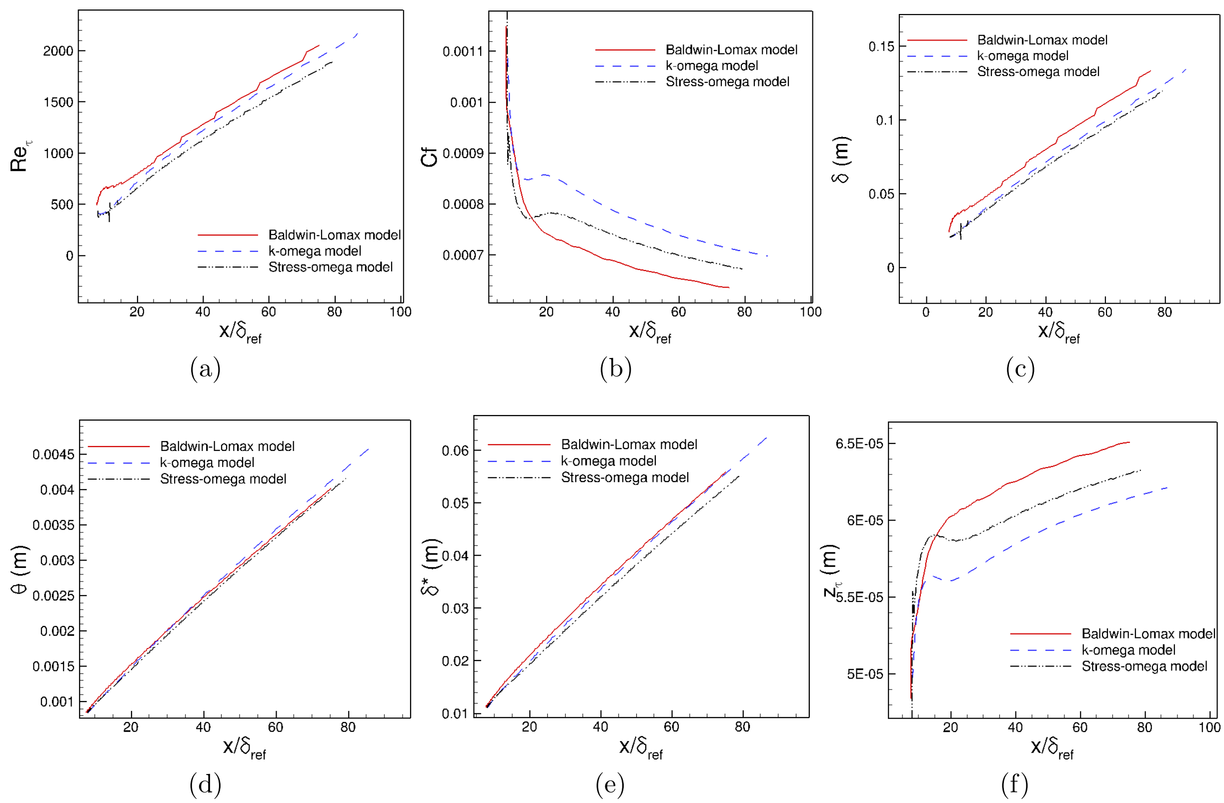

Figure 1: Streamwise distribution of (a) Re_τ, (b) Cf, (c) δ, (d) θ, (e) δ^* and (f) z_τ.

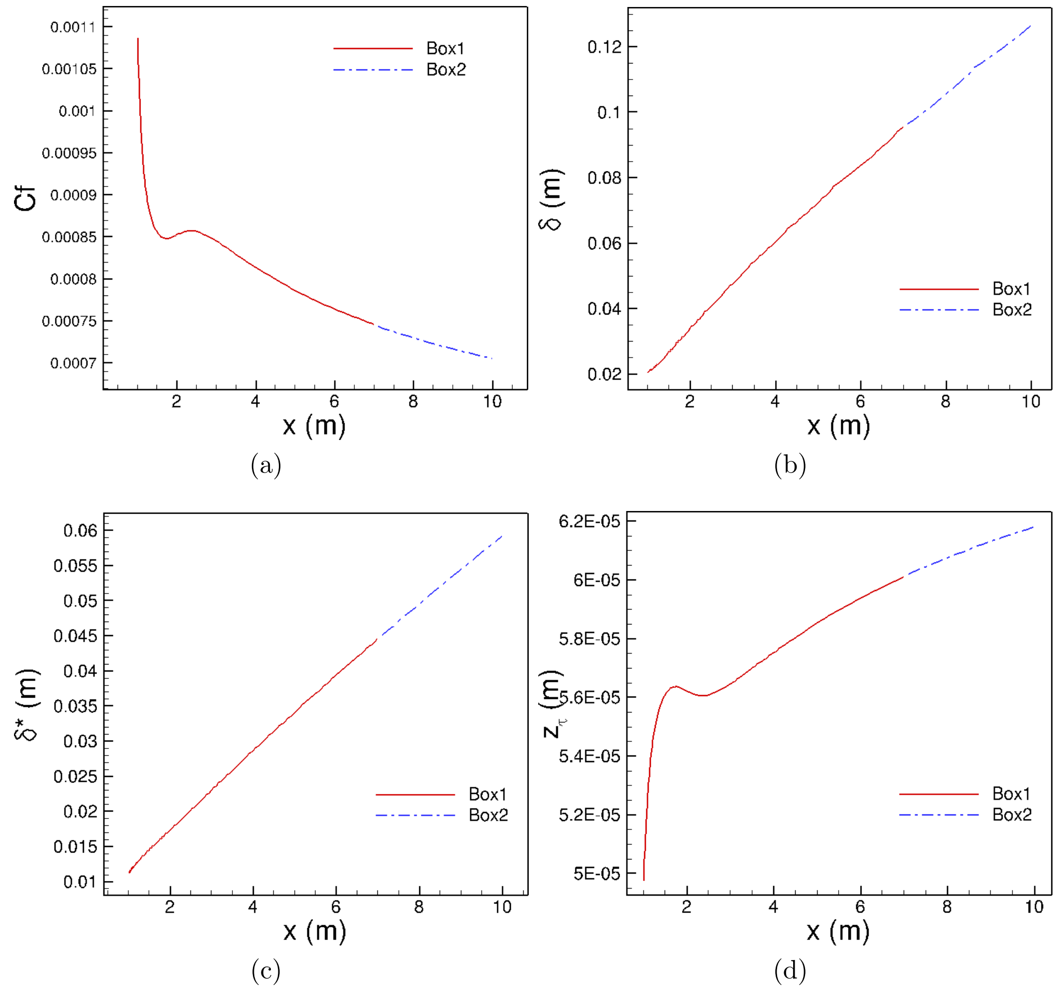

Figure 2: Streamwise distribution of (a) Cf, (b) δ, (c) δ^* and (d) z_τ for restart problem.

δ_{ref} (mm)	Re_τ	z_τ (μm)	u_τ (m/s)	θ (mm)	δ^* (mm)
123	2000	61.7	38.2	4.3	58.3

Table 1: Parameters at the reference location.

$N_x \times N_y \times N_z$	L_x/δ_{ref}	L_y/δ_{ref}	L_z/δ_{ref}	Δx^+	Δy^+	Δz^+_{min}	Δz^+_{max}
$4140 \times 1400 \times 2400$	20.0	3.63	20.0	9.63	5.14	0.51	5.33

Table 2

δ(mm)	Re_τ	z_τ(μm)	u_τ(m/s)	θ(mm)	δ^* (mm)
23.77	453.1	52.6	45.07	0.948	12.9

Table 3: Parameters for Case M6Tw076 at the station $x_a = 54.1\delta_i$.

Case	$N_x \times N_y \times N_z$	L_x/δ	L_y/δ	L_z/δ	Δx^+	Δy^+	Δz^+_{min}	Δz^+_{max}
M6Tw076	$1600 \times 800 \times 500$	34.08	9.09	23.06	9.63	5.14	0.51	5.33
M6AI	$1920 \times 320 \times 500$	40.90	3.63	23.06	9.63	5.14	0.51	5.33

Table 4: Grid resolution and domain size for the direct numerical simulations. L_x, L_y, and L_z are the domain size in the streamwise, spanwise, and wall-normal directions, respectively. Δx^+ and Δy^+ are the uniform grid spacing in the streamwise and spanwise directions, respectively, with the viscous length scale $z_\tau = 52.6\mu$m being that at $x/\delta_i = 54.1$. Δz^+_{min} and Δz^+_{max} are the minimum and maximum wall-normal grid spacing for $0 \leq z/\delta_i \leq 5$. $\delta_i = 13.8$mm

3 Equation and Transformation Details

3.1 Coordinates Transformation

Physical coordinates (s, n). Transformed coordinates (ξ, η)

$$\begin{aligned} \xi(s) &= \int_0^s \overline{\rho}_e \tilde{u}_e \mu_e ds \\ \eta(s,n) &= \frac{\overline{\rho}_e \tilde{u}_e}{\sqrt{2\xi}} \int_0^n \left(\frac{\overline{\rho}}{\overline{\rho}_e} \right) dn \end{aligned} \tag{1}$$

The dependent variables are transformed according to:

$$\begin{aligned} F(\xi,\eta) &= \frac{\tilde{u}}{\tilde{u}_e}, \Theta(\xi,\eta) = \frac{\tilde{T} - \tilde{T}_e}{\tilde{T}_e} \\ V(\xi,\eta) &= \frac{2\xi}{\overline{\rho}_e \tilde{u}_e \mu_e} \left[F\left(\frac{\partial \eta}{\partial s}\right) + \frac{\overline{\rho}\tilde{v}}{\sqrt{2\xi}} \right] \\ K(\xi,\eta) &= \frac{k}{\tilde{u}_e^2}, \hat{W}(\xi,\eta) = \frac{2\xi\omega}{\tilde{u}_e^2}, \hat{\varepsilon}(\xi,\eta) = \frac{2\xi\tilde{\epsilon}}{\tilde{u}_e^4} \end{aligned} \tag{2}$$

where $\frac{\partial \eta}{\partial s} = \frac{1}{2\xi} \overline{\rho}_e \tilde{u}_e \mu_e \eta(s,n)$

The transformed continuity equation is:

$$2\overline{\xi} \frac{\partial F}{\partial \overline{\xi}} + \frac{\partial V}{\partial \eta} + F = 0 \tag{3}$$

where $\overline{\xi} = \frac{\xi}{\rho_\infty U_\infty \mu_r}$. μ_r is the value of μ for $T = T_r = U_\infty^2 / c_p$.

3.2 Wall-normal velocity

If$(Re >> 1)$, then $\frac{\partial F}{\partial \overline{\xi}} \approx 0$. We get the following equation.

$$\frac{\partial V}{\partial \eta} = -F \tag{4}$$

thus $dV = -F \times d\eta$. Program EDDYBL uses this relation to calculate the wall-normal velocity.

From the equation 2 and $\frac{\partial \eta}{\partial s} = \frac{1}{2\xi} \overline{\rho}_e \tilde{u}_e \mu_e \eta(s,n)$, we can get

$$\tilde{v} = \frac{\overline{\rho}_e \tilde{u}_e \mu_e}{\sqrt{2\xi}} (V - F) \frac{1}{\overline{\rho}} \tag{5}$$

4 Program EDDYBL Overview

Program **EDDYBL** is a two-dimensional and axisymmetric, compressible boundary-layer program for laminar, transitional and turbulent boundary layers.

In order to run Program **EDDYBL**, the following files are needed.

File Name	Function
eddybl.exe	Executable Program **EDDYBL**
eddybl_data.exe	Input-data preparation Program **EDDYBL_DATA**
eddybl_plot.exe	Plotting Program **EDDYBL_PLOT**
eddybl_start.exe	Initial-profile Program **EDDYBL_START**

Table 5: Files for Program **EDDYBL**.

1. The first step is to run Program **EDDYBL_DATA**. After successfully completing the input data, click on the button with the label "Write Input-Data Files". This runs Program **EDDYBL_START**, which generates initial profiles that will be used by Program **EDDYBL**.

2. Now click on the button with the label "Run Program EDDYBL". This runs Program **EDDYBL**.

3. Click on "View Program Output" to view, print and edit output file **eddybl.prt**.

4. Click on the "Plot Computed Profiles" button to create a plot.

5 Setup for Case M6 LargeSpan

5.1 Opening Menu

Figure 3 shows the main menu after running Program **EDDYBL_DATA**. For the current case, you must make the following four changes.

1. Select the k-epsilon model (Jones-Launder)

2. Select Sarkar compressibility term

3. Select SI units

4. Select a Long printout

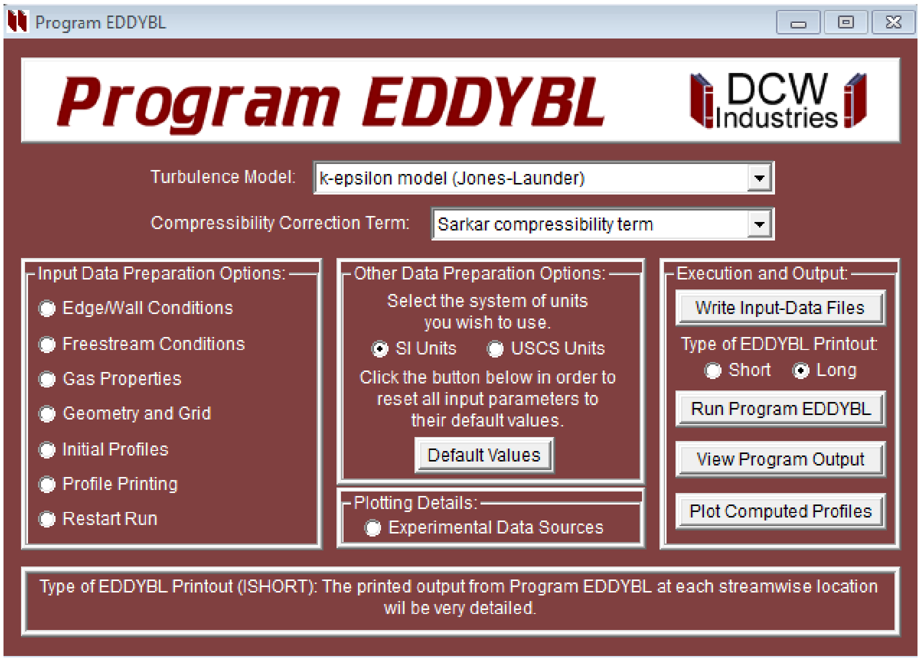

Figure 3: Opening menu of Program **EDDYBL_DATA** after modification.

5.2 Freestream Conditions

Click on the "Freestream Conditions" button will bring you to the menu that accepts input for freestream conditions. Change the total pressure to $P_{t\infty} = 9.17683 \times 10^5$ pa. Then change the total temperature and Mach number to $T_{t\infty} = 432.1$ K and $M_\infty = 5.86$, respectively.

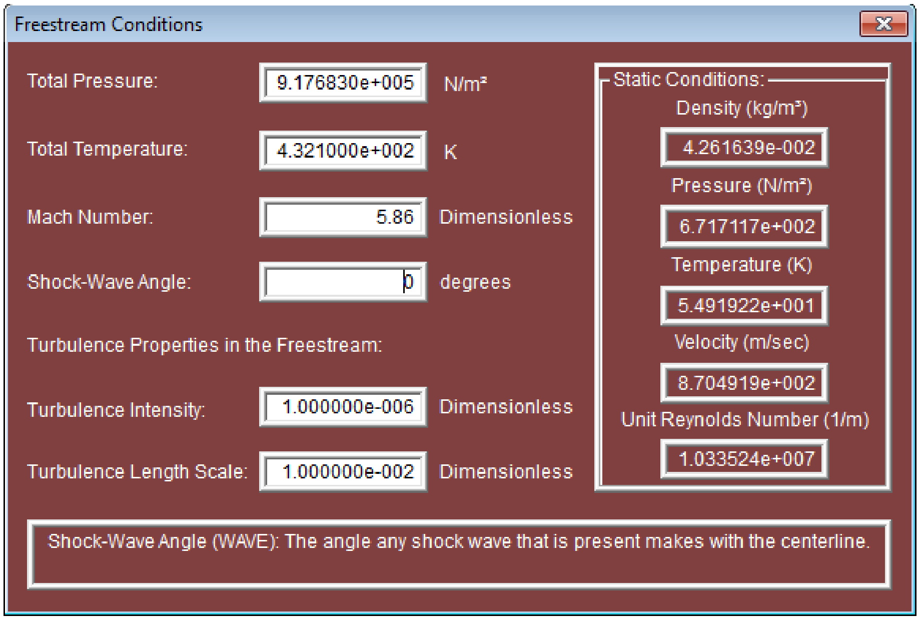

Figure 4: Freestream-Conditions menu of Program **EDDYBL_DATA** after modification.

5.3 Geometry Grid

Click on the "Geometry and Grid" button. You will set geometric-progression ratio, k_g, initial stepsize, Δs, initial arclength, s_i, and maximum length, s_{stop}.

Keeping the default value $k_g = 1.07$ and number of grid points normal to surface 101 can satisfy the constraint $y^+ < 1$. The initial stepsize can be as large as triple the boundary-layer thickness.

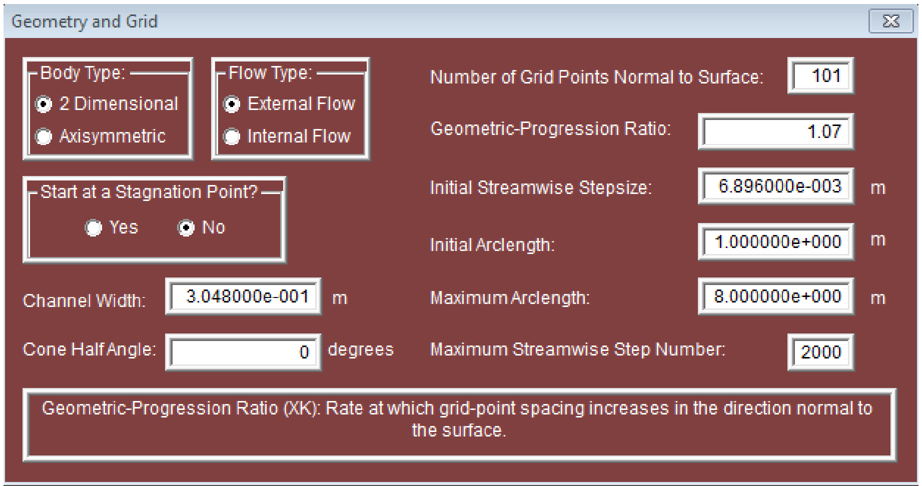

Figure 5: Geometry and Grid menu of Program **EDDYBL_DATA** after modification.

5.4 Edge/Wall Conditions

Click on the "Edge/Wall Conditions" button. For any boundary-layer computation, at a minimum, you must specify freestream pressure and either surface temperature or surface heat-transfer rate.

Click on the "Temperature" button. In the bottom section of the menu labeled "Edge/Wall Property Arrays", change the values of boundary-layer edge pressure and surface temperature temperature to $p_\infty = 673.6$ pa and $T_w = 300$ K, respectively, on "Line No." 1 and 2.

The values of s on "Line No." 1 and 2 are the minimum s_{min} and maximum s_{max} value of the streamwise locations. Make sure $s_{min} < s_i$ and $s_{max} > s_{stop}$.

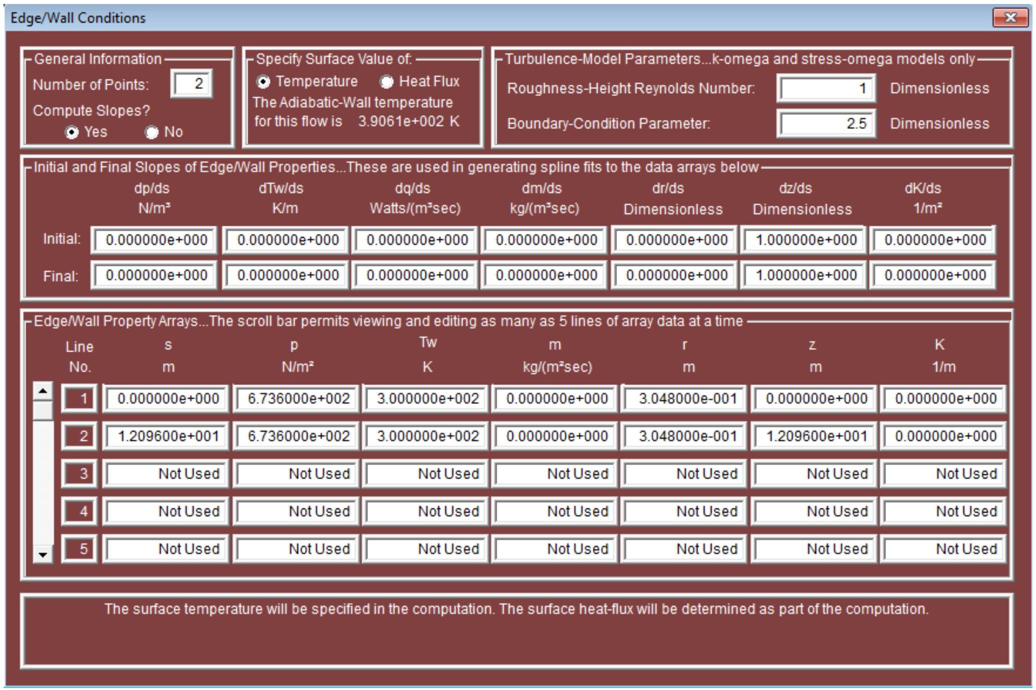

Figure 6: Edge/Wall-Conditions menu of Program **EDDYBL_DATA** after modification.

5.5 Initial Profiles

Click on the "Initial Profiles" button. Change the values of skin friction, Reynolds number based on momentum thickness, shape factor and initial boundary-layer thickness to $C_f = 0.00117076$, $Re_\theta = 8737$, $H = 13.2$ and $\delta = 0.020689$ m, respectively.

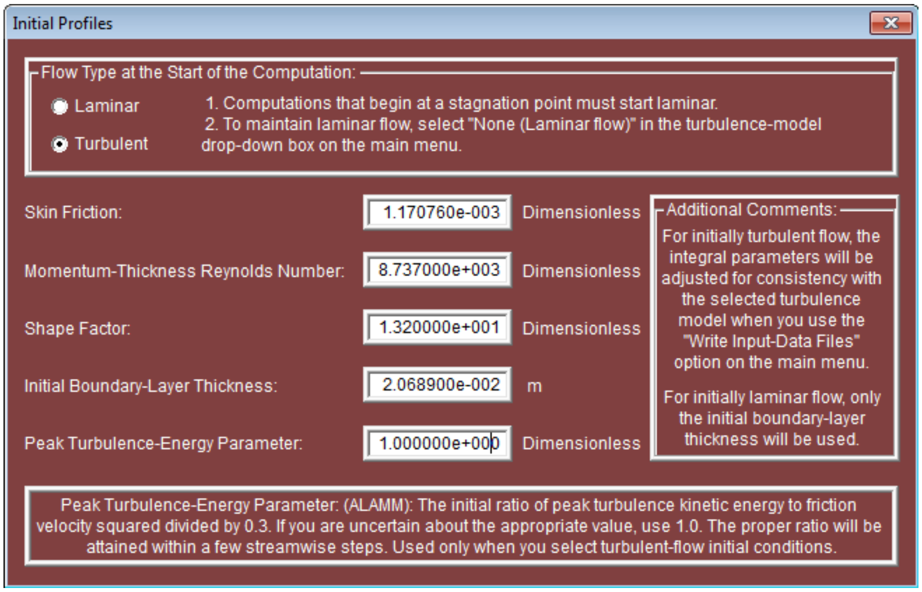

Figure 7: Initial-Profiles menu of Program EDDYBL_DATA after modification.

5.6 Gas Properties

The "Gas Properties" menu includes several thermodynamic properties. Sutherland law can be written as:

$$\mu = \mu_r \frac{T^{1+\omega}}{S+T} \tag{6}$$

The input parameters $SU = 110.4$, $VISCON = 1.458 \times 10^{-6}$ and $VISPOW = 1.5$.

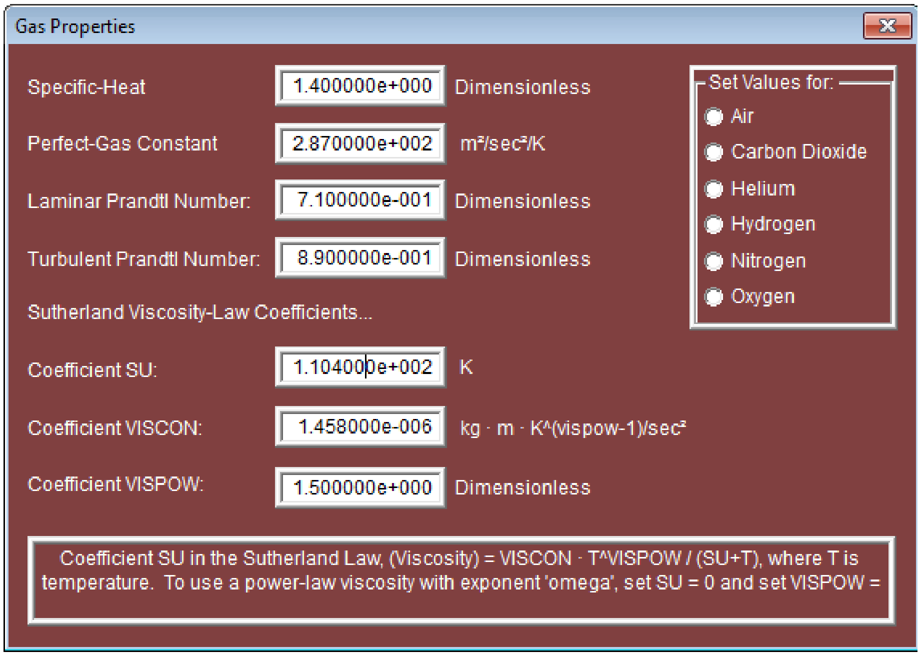

Figure 8: Gas-Properties menu of Program EDDYBL_DATA after modification.