CML Air Bearing Design Program
User's Manual(Version 4)

1. Introduction

This manual describes the CML Air Bearing Design Program (version 4) with its new Windows interface, as well as the revised input data format. This manual is also available as a windows help file and which is included with the CML Air Bearing Design Program distribution files.

The Windows interface has been developed to replace the previous interface written in Matlab, which is a commercial mathematics and data visualization package. The Windows interface consists of a pre-processor that generates input data files readable by the solver, and a post-processor for visualization of output files generated by the solver.

The air bearing solver is written in FORTRAN 77 and has been tested under Linux, Digital UNIX, IBM AIX as well as PC/Windows. It can be easily ported to other platforms with a F77 compiler. The interface is a 16-bit Windows application that runs under both Windows 3.1 and Windows 95.

2. Installation

There are two parts in the package: the solver and the interface. They are packed in two ZIP files: quick413.zip and cmlair16.zip respectively.

2.1 Air Bearing Solver

Create a directory to hold the solver files. Unzip quick413.zip into that directory. The files are organized into a few sub directories.

2.1.1 Files and Installation

The following is a description of the contents:

Files in the top level directory are **make** utilities: **makefile**, **make.bat**, **make, and sys_def.** They are only useful if the user wants to recompile the source code.

Sub directory **src/** contains the source code and includes files: **version.fi**, **size.fi**, **common.fi**, **openout.fi**, **quick.f**, **reynolds.f**, **init.f**, **grid.f**, **mult.f**, **misc.f**, **util.f**, **force.f**, **inv.f**.

Sub directory **sys/** contains the compiler specific (UNIX or PC/Watcom) **makefile** definitions: **sys_unix**, **sys_win**.

Sub directory **ibm/** contains the pre-compiled binary file **quick413** for IBM RS/6000 systems.

Sub directory **dec/** contains the pre-compiled binary file **quick413** for DEC Alpha machines.

Sub directory **pc/** contains the Windows executable **quick413.exe** generated with the Watcom compiler. To help the user re-compile the code, **make.exe** is also included. It is a PC port of the free GNU make utility, taken from the DJGPP package. The source code is generally available from GNU.

Sub directory **obj/** contains the object codes generated during compilation. It is empty at the time of distribution.

Sub directory **sample/** contains a set of sample data files: rail.dat and run.dat. They can be used to check whether the solver is properly installed. The interface should also be able to read them once installed.

For platforms where the binary file is available, the user needs only the binary file. After setting the proper path for the binary, simply go to the **sample**/ directory and try to run it with the sample data files. However, the user must re-compile the code if the target platform is not directly supported. Re-compilation is also necessary when the user wishes to change some array limits. The process of re-compilation is discussed in the next section.

2.1.2 Compiling the Source Code

As described in the last section, some make utilities are provided to facilitate user compilation. Only the Watcom compiler is directly supported on the PC. Before using the Watcom compiler, append the following line to **autoexec.bat**:

set finclude= %finclude%;src

Make sure that this line appears after the original statement of "set finclude=..." (needed in setting up the Watcom compiler). Run **autoexec.bat** or reboot for the change to take effect.

If nothing in the source code needs to be altered, simply type **make** in the top distribution directory on all platforms.

On the PC, **make.bat** is executed first. It first copies **sys_win** from the **sys/** directory to **sys_def** which contains Watcom specific variable definitions for **makefile**. **Make.bat** then invokes **pc/make.exe** to make the binary.

On UNIX workstations, a shell script **make** in the current directory is invoked. It first copies **sys_unix** from the **sys/** directory to **sys_def** which contains UNIX specific variable definitions for **makefile**. The script then starts the **make** utility on the workstation to generate the binary. It assumes that **/bin/make** is the path for the **make** utility**.** If this is not the case, it should be changed in the shell script.

The binary file generated by **make** is in the top level directory. On UNIX machines, it is named **quick413**, while on PC it is **quick413.exe**.

In most cases, the only files the user wants to change are **size.fi** and **openout.fi**. The **size.fi** file sets the grid size, rail and wall profile array size limits. These variables are self-descriptive and can be easily modified. The second file is concernded with the problem of writing and reading many numbers in one long line. If there is an input-output problem apart from the initial reading of the **rail.dat** and **run.dat** files, check this file and make modifications. It is self-explanatory.

If the user does not often modify the code and re-compile, the object files in **obj/** generated by the compiler can be deleted to save some disk space. Just type **make clean** after compilation.

2.2 Windows Interface Installation

The installation package for the Windows interface is a zipped file **cmlair16.zip**. Unpack the file into a temporary directory with an unzip utility such as **pkunzip** from Pkware. As an example, we will assume the directory is **c:\cmltemp**, and the Windows directory is **c:\windows**.

Run the **c:\cmltemp\setup.exe** program and follow the instructions. Choose an installation directory. After installation, a program group **cmlair** and an icon should be automatically generated in Windows. The executable of the Windows interface is **cmlair16.exe**. Before the program can be used, **run c:\cmlair\regsvr.exe c:\windows\system\vcfi16.ocx** in Windows (assuming the interface was intalled in c:\cmlair).

3. Interface Guide

The interface program can be invoked by double clicking the program icon in Windows. When the interface starts, it first presents an image with the CML logo. Then a main menu bar appears at the top with a tabbed Window below it.

3.1 Menu Bar

The menu bar has two menus: *File* and *Options*.

3.1.1 *File* menu

There are four selections under the *File* menu: *Open*, *Save*, *Save As*, *Convert Old* and *Exit*. A dialogue box for file selection appears if *Open* is clicked. After a directory and file name are chosen, the program tries to load **rail.dat** and **run.dat** in the specified directory. The file name selected has no significance. Similarly for *Save* and *Save As*, the program saves the input files as **rail.dat** and **run.dat**. These are the only input files to the solver. This implies that the user should create a different sub directory for each case.

Convert Old lets the user to convert the prior release **quick300** input files **steady.def**, **rail.dat** and **multcase.dat** to the current form. It works just like opening and then saving files. Since there are significant changes in the input format and solver options, the user needs to check the converted data carefully. Choosing *Exit* terminates the interface session.

3.1.2 *Options* menu

This menu contains two sub-menus: *Slip Model* and *Solution*.

Slip Model: choose from *1-order slip*, *2-order slip* and *F-K Boltzmann* models. The F-K model is the default.

Solution: calculate pressure at *Fixed Attitude* or obtain steady state *Fly Height* iteratively. The *Fixed Attitude* option turns off several of the other functions. If many input frames in the tabbed Parameter window(next section) are disabled (unavailable), this option may be on!

3.2. Tabbed Parameter Window

Most of the input parameters are entered through the tabbed window shown in Figure 1. The parameters are grouped into six tabs: **General, Rails**, **Wall Profiles**, **Partial Contact**, **Grid** and **Run Setup**.

3.2.1 **General** Tab

The parameters under the **General** Tab are divided into several frames: *Slider Geometry*, *Initial Flying Attitude*, *Suspension*, *Points of Interest*, *Convergence* and *Comments*. See Figure 1.

3.2.1.1 *Slider Geometry*

Length, *width and height* : slider dimensions, default values are 2.05 mm, 1.6 mm, 0.43 mm respectively, which is standard for 50% sliders.

Crown, *camber* and *twist*: these are the second order surface topography components superimposed on each other over the whole slider. Positive crown and camber values represent convex parabolas in the length and width directions, respectively. With a positive twist, the inner leading edge and outer trailing edge are recessed (larger spacing) while the outer leading edge and inner trailing edge are raised (smaller spacing).

Taper length and *taper angle*: a wedge with the given *taper angle* starting at *taper length* from the leading edge will be removed from the slider. In some cases, the taper is machined before the etching process, resulting in a recessed *ramp* in the frontal area. This area can be modeled by defining a *ramp* (see 3.2.2.3).

3.2.1.2 *Initial Flying Attitude*

An *initial flying attitude* is needed to start the calculation, no matter whether the goal is to obtain the pressure for fixed attitude or to predict the fly height. In the former case, the initial attitude is given, while in the latter case, a guessed attitude is used. The attitude has three components: *TEC*, *pitch* and *roll*.

TEC is the height of the trailing edge center at the zero recess plane. It is only a reference point, not a physical one. To track the fly heights at physical points on a slider, define *points of interest* (see 3.2.1.4). In version 3 (**quick300**), *TEC* must be positive. However, in certain designs, *TEC* can be negative at steady state if the entire trailing edge is recessed. Negative *TEC* is allowed in this version to allow faster convergence to steady state fly height in these situations.

For positive *pitch*, the spacing at the leading edge is larger than at the trailing edge, and the spacing at the outer rail is smaller than at the inner rail for positive *roll*. **IMPORTANT**: the *roll* sign convention has been changed in this version from that in the previous version in order to comply with the IDEMA standard.

3.2.1.3 *Suspension*

The parameters in this frame are needed if the fly height is sought under a given suspension load. The code searches for the steady state flying attitude using the Quasi-Newton method.

Load: suspension load.

POffset: from the center of the slider, positive value moves load point towards trailing edge.

ROffset: from the center of the slider, positive value moves load point towards outer rail.

PTorque: static pitch torque to create the static pitch.

RTorque: static roll torque to create the static roll. **Note the new sign convention for roll angle.**

3.2.1.4 *Points of Interest*

These points are used to track the fly heights of the sliders. Up to four points can be specified. The origin of the coordinate system is the inner leading edge. The input format consists of one pair of x and y (separated by a comma or space) coordinates per line.

3.2.1.5 *Convergence*

There are the two convergence criteria for the solution of the Reynolds equation and the fly height iteration.

Reynolds Equation: normalized residual for Reynolds equation. The default value of 10^{-7} is usually enough. A smaller number may be needed in some cases.

Load error: the normalized difference between suspension load and the bearing load, including torque balance. This is used in finding the steady state fly height. The default value is 10^{-3}.

3.2.1.6 *Comments*

This text box accepts comments about the current case.

3.2.2 **Rails**

Use this tab to create and modify rails (Figure 2). In this version, each edge of a rail can have a different **wall profile**. See section 3.2.3 for instructions on how to create wall profiles.

3.2.2.1 *Rail Points*

This text box is for entering rail shapes. On each line, type in the x, y coordinates of a rail point and the **wall profile** index (separated by space or comma) for the edge starting at this point. Use zero for the wall profile index wherever a vertical wall is needed. The origin of the rail point coordinates is at the inner leading edge.

3.2.2.2 *Rail Index*

The index of the current rail is displayed. Use the spin buttons on the right to switch to other rails.

3.2.2.3 *Rail Type*

A rail can either be a *step* or a *ramp*. A step has a uniform *recess height*. A *ramp* is a plane with arbitrary orientation. The *recess heights* for the first three rail points must be specified for a *ramp*. **IMPORTANT**: never have three collinear points for a *ramp*.

3.2.2.4 *Base Recess*

This is the recess height for all points not covered by any rail.

3.2.2.5 Miscellaneous

The command buttons *Add*, *Delete* and *Update* are used to add a rail, delete a rail and update the changes made to a rail, respectively.

The box at the lower right corner shows the number of *total rails*.

3.2.3 **Wall Profiles**

In Section 3.2.2, it is mentioned that for each rail edge, a **wall profile** identified by an index can be specified. These profiles are created and modified in the **Wall Profiles** tab (Figure 3).

3.2.3.1 *Profile Index*

The index for the current profile is shown in the box. Click on the spin buttons to select other profiles.

3.2.3.2 *Profile*

The *Profile* frame contains the coordinates of points defining the profile. The two coordinates are: normal distance from the nominal edge and the recess height. A negative normal distance indicates that the point is inside the rail boundary.

3.2.3.3 Miscellaneous

The box *Total Profiles* at the lower left corner indicates the total number of wall profiles defined.

The command buttons *Add*, *Delete* and *Update* are used to add a profile, delete a profile and update the changes made to a profile, respectively.

The lower right part is a graph plotting the current profile. Note that the recess heights are plotted as negative numbers.

3.2.4 **Partial Contact**

Partial Contact models are incorporated into the current version (Figure 4).

3.2.4.1 *Model*

Two models can be selected from this drop down menu: the Greenwood-Williamson or the Elastic-Plastic model. Benchmarks show that these two models produce similar results.

3.2.4.2 *Surface*

A few surface roughness parameters.

Asperity Density: aerial density of asperities.

STD of Asperity Height: standard deviation of asperity heights.

Radius of Curvature: mean radius of curvature for asperities.

3.2.4.3 *Material*

This frame contains material properties of the disk: *Young's modulus*, *Poisson's Ratio*, *Yield strength* and *friction coefficient*.

3.2.5 **Grid**

This tab deals with the computation grid (Figure 5).

3.2.5.1 *Computation Grid*

There are several grid generation options.

Initial Grid: either use the existing grid or generate a new grid using a piece-wise geometric series. If the first option is chosen, the solver will use the existing grid data files (x.dat and y.dat). The latter option is discussed in detail below.

Symmetry in Width: when checked, the grid needs only to be specified for half the width, the other half is generated using symmetry.

Adaptive Grid / *Fixed Grid*: In order to make better use of the available grid size, an adaptive grid method is implemented. If the *adaptive grid* option is on, the grid is redistributed according to pressure gradients obtained from the initial calculation. With *fixed grid*, only the *initial grid* is used. The parameters controlling the *adaptive grid* are described below.

3.2.5.2 *Adaptive Grid*

These are the parameters controlling the *adaptive grid*.

Pressure Gradient: the grid density function used to adjust the grid distribution is based on the pressure gradient obtained from the initial calculation. In order to compute the grid density in one direction, e.g., the x direction, the user can choose to use either the *maximum* or *averaged* pressure gradient along all the y locations.

Max/Min: the pressure gradient in some areas may be very small (e.g., a fully recessed region), but some minimum grid concentration may be needed the calculation. The user can specify the *Max/Min* pressure gradient (grid density) ratio. A smaller ratio generates a more uniform mesh.

DecayFactor: the pressure gradient may change abruptly in some regions. However, such abrupt changes in the grid distribution should be avoided to reduce discretization error. A smoothing method has been implemented so that the pressure gradient at one point not only affects the grid density at that point, but also has an exponentially decaying influence over neighboring locations. The larger the *DecayFactor*, the more abruptly the grid density changes.

3.2.5.3 *Geometric Series*

A new grid can be generated with a piecewise geometric series.

Total Grid Sizes: total number of grid lines in the x and y directions. The program uses a multi-grid method to achieve solver efficiency and requires that the grid numbers have the format (16k + 1), where k is an integer.

X Control Points and *Y Control Points*: a set of points by which the slider length and width are cut into segments, respectively. For example, two points generate three segments. Within each segment, the successive grid size changes at a fixed ratio (geometric series).

X Grid Indices and *Y Grid Indices*: grid indices at *X Control Points* and *Y Control Points*, respectively.

X Grid Ratios and *Y Grid Ratios*: the ratios of successive grid sizes in each segment.

Note that if *Symmetry in Width* is checked in Section 3.2.5.1, only half of the width is needed here.

If the command button *Update Grid* is clicked, a graph showing the updated grid pops up (Figure 6).

3.2.6 **Run Setup**

This tab is used to setup the operating conditions (Figure 7).

3.2.6.1 *Radial Position/Skew*

Specify one *Radial Position* and the corresponding *Skew* on each line. Up to ten positions can be entered.

The order of *Radial Positions* should be from OD to ID, otherwise, the interface will rearrange them that way! The reason is that the solver only generates adaptive grid at one radial position and uses it for all other cases. Since the pressure peak is usually higher at the OD, the adaptive grid should be generated there.

For positive skew, the flow goes from the outer rail towards inner rail. **IMPORTANT**: the *skew* sign convention has been changed in this version from that in the previous version in order to comply with the IDEMA standard.

3.2.6.2 *RPMs*

Enter a series of *RPMs* separated by commas or spaces. Normally only the operating RPM is needed. Multiple *RPMs* are used for a quasi-static take-off study. The order should be from high *RPM* to low *RPM*, otherwise the interface will re-order the numbers.

3.2.6.3 *Altitudes*

Multiple *Altitudes* can be used to study altitude sensitivity. The order should be from low altitude to high altitude, otherwise the interface is going to re-order the numbers. If nothing is entered, then the *Air* parameters in the frame below are used. Otherwise, the *Air* frame is disabled.

3.2.6.4 *Air*

Specify the *ambient pressure*, *mean-free-path* and *viscosity*.

3.2.6.5 *Sensitivity Increments*

In order to obtain the sensitivity of slider performance with respect to certain parameters, these parameters are incremented by specified amounts. Only a positive value is needed. The program will do both negative and positive increments. Nothing is done for parameters with zero increment.

The following parameters are currently included: _Crown_, _Camber_, _Twist_, _TaperLength_, _TaperAngle_, _Load_, _PTorque_, _RTorque_ and _Base Recess_. Note that POffset and ROffset are not listed, because they can be deduced from _PTorque_ and _RTorque_. When _Base Recess_ is changed, the wall profiles that end with the same recess height have to be adjusted accordingly. The points on the profile outside the nominal edge scale linearly with recess in the vertical direction. There are two methods to adjust the wall profile width: _proportion_ or _fixed width_. _Proportion_ will also scale width linearly with recess to keep the same aspect ratio, while _fixed width_ only allows points to move vertically.

3.2.6.6 Miscellaneous

If _Calculate Stiffness_ is checked, the program calculates and outputs a 3x3 stiffness matrix for each basic case across the disk radius. It represents the ratio of the change in bearing force components (bearing load, pitch moment and roll moment) over the change in displacement components (height, pitch and roll). Note that the sign convention has been changed for the stiffness matrix elements so that the main diagonal elements should normally be positive. A more detailed description can be found in the source code comments in **stiffness** subroutine in **misc.f**. The stiffness results are appended in the file **result.dat**. See 3.4 for a detailed description of the file **result.dat**.

Since the pressure data files are rather large, especially when there are many runs with a large grid, they are only saved when _Save Pressure_ is checked. Even then, only the pressure data for basic cases across the disk radius will be saved. Three files will be saved for each radial position: **press***num***.dat**, **cprss***num***.dat** and **mflow***num***.dat**, where *num* is the index for the radial position(for example, **press01.dat** ...). Note again that the order should be from OD to ID. See 3.4 for details on output data files.

3.2.7 A Tutorial

You may have noticed that the numbers in the figures used in the above sections are actually different from the default values. This is because the figures are actually taken from a sample problem. Now it is time to put everything together and look at a complete example.

First, start up the interface by double clicking the program icon.
Click on the Options menu. Make sure *F-K Boltzmann* is selected under the *Slip Model* sub menu and *Fly Height* is selected under the *Solution* sub menu.

Select the *General* tab in the tabbed window. Enter all the parameters as shown in Figure 1.

The rails are created next. Select the *Rails* tab. In the *Rail Points* frame, enter the numbers as shown in Figure 2. The first two columns are the x and y coordinates for the rail points. The third column contains the wall profile indices for each edge. The wall profiles are defined later.

After clicking the *Add* button, the rail shape is drawn in a new window titled *Draw Rails*, as shown in Figure 3. Go back to the *Rails* tab. In the *Rail Type* frame, choose *Step* and set the *Recess Height* to 1 μm. Click on the *Update* button. Near right bottom, set the *Base Recess* to 4 μm.

Now click the *Mirror* button in the *Rails* tab, another rail is created and drawn (Figure 9). This is the mirror image of the first rail with respect to the center line. It also inherits the *Recess Height* value of the first rail.

Enter the *Rail Points* for the third rail as shown in Figure 10. Click the *Add* button. Set *Recess Height* to 0. Click *Update*. Create the fourth rail similarly (Figure 11). Figure 12 shows all four rails.

Note that all edges in the first two rails use wall profile No. 1 and all edges in the last two rails use wall profile No. 2. These wall profiles are defined next.

Select the *Wall Profiles* tab. Enter the coordinates in the *Profile* frame as shown in Figure 3. Click on the *Add* button. The new profile is now plotted in the lower right corner. Note the recess depths are negative in the plot. This is necessary in order to orient the plot properly. By convention, recess depths are represented by positive numbers in the program.

The second wall profile can be created similarly (Figure 13).

Two contact models are included in this version*:* *Greenwood-Williamson* and *Elastic-Plastic*. They can be selected in the *Partial Contact* tab. Enter the parameters as shown in Figure 4.

Select the *Grid* tab. Enter the grid parameters as shown in Figure 5. The adaptive grid is used with a uniform initial mesh. Click on the *Update Grid* button. A new window opens up displaying the initial mesh with the rail shapes superimposed on it (Figure 6).

Select the *Run Setup* tab. Enter the parameter as shown in Figure 7.
Since the *Altitudes* are specified explicitly, the *Air* frame is disabled.

All the parameters have been entered. The next step is to save them into the input files. Each case should have its own directory. Create a directory for the current case if you have not done so. Next click on the *File* menu and choose *Save As*. A save file dialogue pops up. Select the correct drive and directory. The actual *File Name* entered is not important. Click on *OK* and the two files **rail.dat** and **run.dat** will be saved in the selected directory. The solver can now use these two files as input. The format of the input files is discussed in the next section.

3.3 Input Data Files

There are only two input data files in this version: **rail.dat** and **run.dat**. The first file describes the slider geometry, while the second one prescribes the test condition. There have been some changes in the input format from Version 3.

3.3.1 **rail.dat**

Sample **rail.dat**:

```
CML VERSION 4.0.13  RAIL.DAT
REPORT BUG TO SHA LU: shalu@cml.me.berkeley.edu
2.050E-03      1.600E-03      4.300E-04
 4              2
 4              1
0.000E00       5.000E-05       1
2.050E-03      5.000E-05       1
2.050E-03      4.000E-04       1
0.000E00       4.000E-04       1
1.000E-6
 4              1
0.000E00       1.550E-03       1
2.050E-03      1.550E-03       1
2.050E-03      1.200E-03       1
0.000E00       1.200E-03       1
1.000E-6
 4              1
0.000E00       1.500E-04       2
2.050E-03      1.500E-04       2
2.050E-03      3.500E-04       2
0.000E00       3.500E-04       2
0.000E00
 4              1
0.000E00       1.500E-03       2
2.050E-03      1.500E-03       2
2.050E-03      1.300E-03       2
0.000E00       1.300E-03       2
0.000E00
 4 5
 0.00E+00  6.00E-06  1.20E-05  2.00E-05
 1.00E-06  3.00E-06  3.60E-06  4.00E-06
```

```
 -1.00E-05  -5.00E-06  0.00E+00       5.00E-06  1.00E-05
 0.00E+00  1.00E-07  3.00E-07  8.50E-07      1.00E-06
2.000E-04         1.000E-02          4.000E-06
2.00E-08           1.00E-08            0.00E+00
 2.025E-03  1.950E-03  2.025E-03  1.950E-03
 2.500E-04  2.500E-04  1.350E-03  1.350E-03
```

The first two lines are the header. The third line contains the slider dimensions in meters: **length**, **width**, **thickness**. The fourth line indicates the **number of rails** and the **number of (different) wall profiles** used.

Next, each rail is defined in succession. The starting line for each rail describes the **number of points** and **style**. A **step** has a **style** value of 1, while a **ramp** has a **style** value of 0. The lines that follow contain the **x and y coordinates** of a rail point and the **wall profile index** for the rail edge starting at that point. Note that the **x and y coordinates** are now in meters instead of normalized, and the **wall profile indices** should be zero for a **ramp**. The final line in a rail description contains the **recess height(or three heights** for a **ramp)** in meters for the rail.

The line that follows the rail definitions contains **the number of wall profile points** for all wall profiles. Next, each wall profile definition occupies two lines. The first line contains the normal distances to the nominal edge for the profile points. Note the unit is now in meters. A negative value indicates that the point is inside the nominal rail boundary, while a positive value otherwise. The second line contains the recess depth in meters for each point. Note that the zero recess reference plane is the same as for all the rail recess depths, rather than the nominal recess for each rail.

The next line contains the **taper length** in meters, the **taper angle** in radians, and the **base recess** in meters. Note the units for the taper from have been changed from Version 3.

The following line gives the crown, camber and twist in meters. Note the order of camber and twist has been changed from that in Version 3.

The final two lines are the **x and y coordinates** for the points of interest. Note the unit is now meters.

3.3.2 **run.dat**

Sample **run.dat**:

```
CML VERSION 4.0.13  RUN.DAT
REPORT BUG TO SHA LU: shalu@cml.me.berkeley.edu
**************Solution Control***************
istiff isolv   ioldg   iadpt   isave
```

1 1 0 1 1
***************Initial Attitude***************
hm(m) pitch(rad) roll(rad)
5.0000E-08 1.0000E-04 0.0000E+00
***************Runs***************************
irad irpm ialt
2 2 2
radii(m)
1.5000E-02 2.3000E-02
skews(deg)
-3.0000E+00 8.0000E+00
RPMs
3.6000E+03 5.4000E+03
altitudes(m)
0.0000E+00 2.0000E+03
***************Air Parameters*****************
p0(pa) al(m) vis(nsm-2)
1.0135E+05 6.3500E-08 1.8060E-05
***************Load Parameters****************
f0(kg) xf0(m) yf0(m)
3.500E-03 2.5000E-05 2.5000E-05
xfs(µNM) yfs(µNM) emax
5.0000E-01 5.0000E-01 1.0000E-03
***************Grid Control******************
nx ny
67 67
nsx nsy isymm
1 1 0
xnt(i), i = 2, nsx

nxt(i), i = 2, nsx

dxr(i), i = 1, nsx
1
ynt(i), i = 2, nsy

nyt(i), i = 2, nsy

dyr(i), i = 1, nsy
1
***************Adaptive Grid*****************
difmax decay ipmax
40 40 0
***************Reynolds Equation**************
ischeme imodel akmax

```
 2           3           1.0000E-07
***************Partial Contact****************
icmodel      stdasp(m)      dnsasp(m-2)
 1          6.0000E-09     1.0000E+12
rdsasp(m)      eyoung(pa)      yldstr(pa)
1.0000E-08     1.0000E+10      1.0000E+12
frcoe          pratio
 0.3           0.3
***************Sensitivities******************
crowninc(m)    camberinc(m)    twistinc(m)
1.0000E-08     1.0000E-08      1.0000E-08
tlnginc(m)     tanginc(rad)    loadinc(kg)
1.0000E-05     1.0000E-03      3.0000E-04
ptrquinc(uNM)  rtrquinc(uNM)   recessinc(m)
5.0000E-01     5.0000E-01      5.0000E-01
iwscale
 1
***************Comments**********************
" This is a test case"
```

Here are some explanations:

Solution Control:

- **istiff**: 1 = calculate stiffness, 0 = no stiffness calculation
- **isolv**: 1 = solve for fly height, 0 = given attitude
- **ioldg**: 1 = use existing grid data, 0 = create new grid
- **iadpt**: 1 = use adaptive grid, 0 = no adaptive grid
- **isave**: 1 = save pressure and mass flow, 0 = don't save

Initial Attitude:

- **hm(m)**: nominal trailing edge height
- **pitch(rad)**: pitch, note the change in units from the previous version
- **roll(rad)**: roll

Runs:

- **irad**: number of disk radii where the solution is sought
- **irpm**: number of RPMs
- **ialt**: number of altitudes, 0 = use Air Parameters
- **radii(m)**: disk radii
- **skews(deg)**: skews corresponding to each disk radii
- **rpms**: RPMs
- **altitudes(m)**: altitudes, lowest one is the base case.

Air Parameters:

- **p0(pa)**: ambient pressure

al(m): mean free path
vis(NS/M^2): viscosity

Load Parameters:
f0(kg): load
xf0(m): load point x offset, origin is at the geometric center now!
yf0(m): load point y offset
xfs(μNM): static pitch torque, note the change of unit
yfs(μNM): static roll torque
emax: convergence criterion of load error

Grid Control:
nx: total x grid number (16k+1)
ny: total y grid number (16k+1)
nsx: number of sections in length
nsy: number of sections in width
isymm: 1 = symmetry in width, 0 = specify entire width
xnt(i), i = 2, **nsx**: x control points in meters, no longer normalized!
nxt(i), i = 2, **nsx**: grid indices at x control points
dxr(i), i = 1, **nsx**: grid ratios for each x section
ynt(i), i = 2, **nsy**: y control points, use half width if **isymm** = 1
nyt(i), i = 2, **nsy**: grid indices at y control points
dyr(i), i = 1, **nsy**: grid ratios for each y section

Adaptive Grid:
difmax: ratio of max/min gradient allowed
decay: smaller value increases smoothness
ipmax: 1 = use maximum gradient, 0 = average gradient

Reynolds Equation:
ischeme: convective term scheme. No available in interface.
0 = upwind
1 = hybrid
2 = power-law; default
imodel: slip model
1 = first order slip
2 = second order slip
3 = FK; default
akmax: convergence criterion for Reynolds equation

Partial Contact:
icmodel: 0 = no contact model
1 = Greenwood-Williamson
2 = Elastic-Plastic

stdasp(m): standard deviation of asperity height
dnsasp(m^{-2}): asperity density
rdsasp(m): mean radius of curvature of asperity
eyoung(pa): Young's modulus
yldstr(pa): yield strength
frcoe: friction coefficient
pratio: Poisson's ratio

Sensitivities:

Zero increment means no sensitivity is calculated for the parameter.

crowninc(m): crown increment
camberinc(m): camber increment
twistinc(m): twist increment
tlnginc(m): taper length increment
tanginc(rad): taper angle increment
loadinc(kg): load increment
ptrqinc(μNM): pitch torque increment
rtrqinc(μNM): roll torque increment
recessinc(m): recess increment
iwscale: used with **recessinc**

0 = stretch the profile, the normal distances are unchanged, only the depths are scaled.

1 = scale the wall profile with recess. For the part of the profile that is outside the nominal rail boundary, the normal distances will change proportionally with recess.

3.4 Output Data Files

There are three basic output files: **result.dat**, **x.dat** and **y.dat**.

The **x.dat** and **y.dat** files are one long line each containing the x grid and y grid respectively.

If <u>*Save Pressure*</u> (3.2.6.6) is checked, the pressure data for the basic cases across the disk radius will be saved. Three files will be saved for each radial position: **press*num*.dat**, **cprss*num*.dat** and **mflow*num*.dat**, where *num* is the index for the radial position(for example, **press01.dat** ...). **press*num*.dat** contains the air bearing pressure matrix. The contact pressure is stored in **cprss*num*.dat**. The mass flow data are written to **mflow*num*.dat**. The mass flow is equivalent to some stream line function. When plotted as contours, a flow pattern is obtained. No particular physical unit is chosen for mass flow, so the absolute number has no meaning. Since the mass flow is obtained on a grid shifted by half a grid cell from the grid in **x.dat** and **y.dat**, another set of grid files **xm.dat** and **ym.dat** are also created.

3.4.1 **result.dat**

The following is the **result.dat** generated with the sample input file **rail.dat** and **run.dat**:

```
CML VERSION 4.0.13  RESULT.DAT
 REPORT BUG TO SHA LU: shalu@cml.me.berkeley.edu
 NUMBER OF DISK RADII:  2
   RADII(MM)   : 23.0000 15.0000
   SKEWS(DEG)  :   8.000  -3.000
 NUMBER OF RPMS:        2
       RPMS        : 5400.00 3600.00
 NUMBER OF ALTITUDES:   2
   ALTITUDES(M):     .00 2000.00
 SENSITIVITY CASE IDENTIFIERS:
   CROWN  : -1,+1    CAMBER: -2,+2         TWIST: -3,+3
   LOAD   : -4,+4  PTORQUE: -5,+5  RTORQUE: -6,+6
   TAPER-L: -7,+7  TAPER-A: -8,+8           RECESS: -9,+9




 RADIUS NO. 1   RPM    NO. 1   ALTIT. NO. 1   SENSI. NO. 0

   ERROR       NOMINAL HM(NM)   PITCH(URAD)    ROLL(URAD)
  .5366E-03       74.5526        97.4190        3.5856

 H(2.025, .250) H(1.950, .250) H(2.025,1.350) H(1.950,1.350)
    72.7230        77.2811        68.7788        73.3369

 MIN. HEIGHT =  67.87 (NM) AT (2.032, 1.310)
 POSITIVE FORCE(G):   3.7561
 NEGATIVE FORCE(G):   -.2579
 CONTACT  FORCE(G):    .0000
 X-SHEAR  FORCE(G):    .0937
 Y-SHEAR  FORCE(G):   -.0187

 STIFFNESS MATRIX
       LOAD(G)    .415202E-01    .262170E-01   -.175599E-03
 P-TORQUE(uN-M)    .102611E+00    .203075E+00   -.518799E-02
```

R-TORQUE(uN-M)   .213759E-01   .917882E-02   .127288E+00
HEIGHT(NM)   PITCH(uRAD)   ROLL(uRAD)

RADIUS NO. 2   RPM   NO. 1   ALTIT. NO. 1   SENSI. NO. 0

ERROR	NOMINAL HM(NM)	PITCH(URAD)	ROLL(URAD)
.7169E-03	55.0433	69.3858	-7.1412

H(2.025, .250)	H(1.950, .250)	H(2.025,1.350)	H(1.950,1.350)
46.6132	49.0687	54.4685	56.9241

MIN. HEIGHT = 45.65 (NM) AT (2.032, .337)
POSITIVE FORCE(G):   3.5199
NEGATIVE FORCE(G):   -.0220
CONTACT FORCE(G):   .0000
X-SHEAR FORCE(G):   .0704
Y-SHEAR FORCE(G):   .0045

STIFFNESS MATRIX

LOAD(G)	.670632E-01	.434416E-01	-.107704E-02
P-TORQUE(uN-M)	.202550E+00	.322121E+00	-.143572E-01
R-TORQUE(uN-M)	-.200479E-01	-.191136E-01	.196978E+00
	HEIGHT(NM)	PITCH(uRAD)	ROLL(uRAD)

RADIUS NO. 1   RPM   NO. 1   ALTIT. NO. 1   SENSI. NO.-1

ERROR	NOMINAL HM(NM)	PITCH(URAD)	ROLL(URAD)
.7353E-03	71.5524	92.0714	3.3781

H(2.025, .250)	H(1.950, .250)	H(2.025,1.350)	H(1.950,1.350)
69.9568	75.4880	66.2409	71.7721

MIN. HEIGHT = 65.23 (NM) AT (2.032, 1.310)
POSITIVE FORCE(G):   3.7604
NEGATIVE FORCE(G):   -.2617
CONTACT FORCE(G):   .0000
X-SHEAR FORCE(G):   .0938
Y-SHEAR FORCE(G):   -.0187

RADIUS NO. 2   RPM   NO. 1   ALTIT. NO. 1   SENSI. NO.-1

ERROR	NOMINAL HM(NM)	PITCH(URAD)	ROLL(URAD)
.6309E-03	51.6885	64.0435	-7.1190

H(2.025, .250)	H(1.950, .250)	H(2.025,1.350)	H(1.950,1.350)
43.6188	47.0479	51.4497	54.8788

MIN. HEIGHT = 42.56 (NM) AT (2.032, .337)
POSITIVE FORCE(G): 3.5214
NEGATIVE FORCE(G): -.0232
CONTACT FORCE(G): .0000
X-SHEAR FORCE(G): .0707
Y-SHEAR FORCE(G): .0045

RADIUS NO. 1   RPM   NO. 1   ALTIT. NO. 1   SENSI. NO. 1

ERROR	NOMINAL HM(NM)	PITCH(URAD)	ROLL(URAD)
.5292E-03	77.5928	102.9010	3.5210

H(2.025, .250)	H(1.950, .250)	H(2.025,1.350)	H(1.950,1.350)
75.3829	78.9779	71.5097	75.1048

MIN. HEIGHT = 70.69 (NM) AT (2.032, 1.310)
POSITIVE FORCE(G): 3.7536
NEGATIVE FORCE(G): -.2541
CONTACT FORCE(G): .0000
X-SHEAR FORCE(G): .0935
Y-SHEAR FORCE(G): -.0187

RADIUS NO. 2   RPM   NO. 1   ALTIT. NO. 1   SENSI. NO. 1

ERROR	NOMINAL HM(NM)	PITCH(URAD)	ROLL(URAD)
.9494E-03	58.5525	74.7487	-7.0545

H(2.025, .250) H(1.950, .250) H(2.025,1.350) H(1.950,1.350)

```
    49.8223       51.3059       57.5822       59.0658

 MIN. HEIGHT =  48.94 (NM) AT (2.032,  .337)
 POSITIVE FORCE(G):   3.5189
 NEGATIVE FORCE(G):   -.0209
 CONTACT  FORCE(G):    .0000
 X-SHEAR  FORCE(G):    .0702
 Y-SHEAR  FORCE(G):    .0045
```

......
(sensitivity calculation for other parameters ommitted)

```
 RADIUS NO. 1   RPM    NO. 1   ALTIT. NO. 1   SENSI. NO.-9

   ERROR      NOMINAL HM(NM)   PITCH(URAD)    ROLL(URAD)
  .1610E-03       77.5524       99.1200        7.6194

 H(2.025, .250) H(1.950, .250) H(2.025,1.350) H(1.950,1.350)
    77.9839       82.6696       69.6026       74.2883

 MIN. HEIGHT =  68.84 (NM) AT (2.032, 1.310)
 POSITIVE FORCE(G):   3.7636
 NEGATIVE FORCE(G):   -.2633
 CONTACT  FORCE(G):    .0000
 X-SHEAR  FORCE(G):    .0938
 Y-SHEAR  FORCE(G):   -.0190


 RADIUS NO. 2   RPM    NO. 1   ALTIT. NO. 1   SENSI. NO.-9

   ERROR      NOMINAL HM(NM)   PITCH(URAD)    ROLL(URAD)
  .5924E-03       55.8462       70.4524       -7.9408

 H(2.025, .250) H(1.950, .250) H(2.025,1.350) H(1.950,1.350)
    47.0029       49.5385       55.7377       58.2733

 MIN. HEIGHT =  46.10 (NM) AT (2.032,  .337)
 POSITIVE FORCE(G):   3.5192
 NEGATIVE FORCE(G):   -.0209
```

CONTACT FORCE(G):   .0000
X-SHEAR FORCE(G):   .0708
Y-SHEAR FORCE(G):   .0046

RADIUS NO. 1   RPM   NO. 1   ALTIT. NO. 1   SENSI. NO. 9

ERROR	NOMINAL HM(NM)	PITCH(URAD)	ROLL(URAD)
.8994E-03	72.7215	96.3402	.8082

H(2.025, .250)	H(1.950, .250)	H(2.025,1.350)	H(1.950,1.350)
69.3374	73.8145	68.4484	72.9256

MIN. HEIGHT = 67.43 (NM) AT (2.032, 1.310)
POSITIVE FORCE(G):   3.7499
NEGATIVE FORCE(G):   -.2516
CONTACT FORCE(G):   .0000
X-SHEAR FORCE(G):   .0934
Y-SHEAR FORCE(G):   -.0185

RADIUS NO. 2   RPM   NO. 1   ALTIT. NO. 1   SENSI. NO. 9

ERROR	NOMINAL HM(NM)	PITCH(URAD)	ROLL(URAD)
.8626E-03	54.5658	68.7130	-6.5175

H(2.025, .250)	H(1.950, .250)	H(2.025,1.350)	H(1.950,1.350)
46.4618	48.8670	53.6310	56.0362

MIN. HEIGHT = 45.45 (NM) AT (2.032, .337)
POSITIVE FORCE(G):   3.5210
NEGATIVE FORCE(G):   -.0227
CONTACT FORCE(G):   .0000
X-SHEAR FORCE(G):   .0701
Y-SHEAR FORCE(G):   .0044

RADIUS NO. 1   RPM   NO. 1   ALTIT. NO. 2   SENSI. NO. 0

ERROR	NOMINAL HM(NM)	PITCH(URAD)	ROLL(URAD)
.4530E-03	65.8378	97.5521	3.7931

H(2.025, .250)	H(1.950, .250)	H(2.025,1.350)	H(1.950,1.350)
64.1257	68.6938	59.9533	64.5213

MIN. HEIGHT = 59.05 (NM) AT (2.032, 1.310)
POSITIVE FORCE(G): 3.7341
NEGATIVE FORCE(G): -.2346
CONTACT FORCE(G): .0000
X-SHEAR FORCE(G): .0879
Y-SHEAR FORCE(G): -.0176

RADIUS NO. 2 RPM NO. 1 ALTIT. NO. 2 SENSI. NO. 0

ERROR	NOMINAL HM(NM)	PITCH(URAD)	ROLL(URAD)
.8447E-03	49.6137	67.5718	-7.0691

H(2.025, .250)	H(1.950, .250)	H(2.025,1.350)	H(1.950,1.350)
41.1779	43.4974	48.9539	51.2734

MIN. HEIGHT = 40.22 (NM) AT (2.032, .337)
POSITIVE FORCE(G): 3.5169
NEGATIVE FORCE(G): -.0194
CONTACT FORCE(G): .0000
X-SHEAR FORCE(G): .0650
Y-SHEAR FORCE(G): .0042

RADIUS NO. 1 RPM NO. 2 ALTIT. NO. 1 SENSI. NO. 0

ERROR	NOMINAL HM(NM)	PITCH(URAD)	ROLL(URAD)
.6483E-03	44.8390	68.4265	-.4451

H(2.025, .250)	H(1.950, .250)	H(2.025,1.350)	H(1.950,1.350)
40.0677	42.4513	40.5573	42.9409

MIN. HEIGHT = 38.53 (NM) AT (2.032, .337)
POSITIVE FORCE(G): 3.7053
NEGATIVE FORCE(G): -.2067

```
CONTACT  FORCE(G):    .0000
X-SHEAR  FORCE(G):    .0668
Y-SHEAR  FORCE(G):   -.0133



RADIUS NO. 2   RPM    NO. 2   ALTIT. NO. 1   SENSI. NO. 0

   ERROR       NOMINAL HM(NM)   PITCH(URAD)    ROLL(URAD)
  .7443E-03       35.7047        45.7431        -3.9767

H(2.025, .250) H(1.950, .250) H(2.025,1.350) H(1.950,1.350)
    28.4240        29.1063        32.7984        33.4807

MIN. HEIGHT =  27.35 (NM) AT (2.032,  .337)
POSITIVE FORCE(G):   3.5181
NEGATIVE FORCE(G):   -.0203
CONTACT  FORCE(G):    .0000
X-SHEAR  FORCE(G):    .0484
Y-SHEAR  FORCE(G):    .0031
```

The top section contains general information on different runs: disk radii, RPMs and altitudes. It also gives the identifiers for different tolerance parameters. The positive and negative signs represent positive and negative increment, respectively. The rest of file contains the results for each case.

The cases are ordered using the following rules. A set of cases with different disk radii going from OD to ID is called a **disk traversal**. The **basic disk traversal** is run first, which has the highest RPM and lowest altitude.

Next the sensitivities with respect to the tolerances are calculated using the basic disk traversal as reference. Only those parameters whose increment is not zero are actually used. The parameters are ordered by the identifiers given in the top section. For each parameter, a disk traversal is performed first with a negative increment of the parameter and then with a positive increment.

Disk traversals are performed next in the order of increasing altitudes.

Finally, disk traversals are performed in the order of decreasing RPMs.

The first line for each case is the case identifier consisting of the radius, RPM, altitude and sensitivity indices. Next the normalized error for load, the fly height at the nominal trailing edge, pitch and roll are given. The fly heights at the four points of interest follow. The minimum fly height point and its location are saved. Various integral forces are summarized next: positive force, negative force, contact force, shear force in x direction and shear force in y direction. If the stiffness calculation is enabled, the stiffness matrices are also saved for the basic disk traversal defined above.

3.4.2. Postprocessing

Included in this version is a post processor for visualization of output files. Users may also visualize output data using Matlab.

3.4.2.1 CML Post Processor (Quick Post)

If the preprocessor interface was properly installed, it should allow direct access to the CML Post Processor (Quick Post) via the *Post Processing* menu item from the *File* menu in the preprocessor interface.

3.4.2.1.1 Files

To open a document for post processing, choose “File : Open” from the main menu. Then, from the file dialog box, choose a file from the directory in which the input and output files from Quick are located. The actual file that you choose is irrelevant. Only the directory matters. This directory is called the “document directory”. (*Note: Quick uses the current working directory as the initial directory for the Quick Post. In other words, if you invoke Quick Post from Quick, you will not have to open any files manually).*

When Quick Post opens a document, it checks for the existence of the following Quick input files **rail.dat** and **run.dat**. If these files are not in the document directory, Quick Post will issue and error message and will not be able to continue. If you receive this error message, check to make sure these files are contained in the document directory.
Quick Post also checks for Quick output files. It first reads **run.dat** to find the number and type of output files that should exist, and then checks for the existence of those files in the document directory. No warnings are issued if these files are not found.

If **rail.dat** and **run.dat** are properly formatted, Quick Post will display an initial default window of the slider rail geometry (See 3.4.2.1.2 Rails).

3.4.2.1.2 Rails

To view the rail geometry of the current slider, choose *Rails* from the *Post* menu. This is a view of the slider rail geometry. Note: Neither wall angles nor taper are displayed. This view is simply a reference for the user. There are no viewing options.

3.4.2.1.3 3-d Air Pressure

To view the air bearing pressure for the current simulation, choose *Pressure Profile* from the *Post* menu. This is a 3-d plot of the air pressure data generated by Quick. Quick Post uses X.DAT and Y.DAT as axis data and PRESS*.DAT as the pressure data. There are several viewing options:

- Dynamic Rotation

  The figure can be dynamically rotated using mouse-trackball style control. Simply double-click the left mouse button and hold down the button after the second click. By moving the mouse, the figure can be rotated as if the mouse was a trackball.

- Menu Options

  Click the right mouse button to get a popup menu with various viewing preferences. These include background color, zoom, Z-scale, and rotation.

3.4.2.1.4 3-d Contact Pressure

To view the contact pressure for the current simulation, choose *Contact Profile* from the *Post* menu.This is a 3-d plot of the contact pressure data generated by Quick. Quick Post uses X.DAT and Y.DAT as axis data and CPRSS*.DAT as the pressure data. The contace pressure plot viewing options are the same as those for the air pressure plot (see 3.4.2.1.3 3-d Air Pressure).

3.4.2.1.5 Mass Flow Contour

To view the mass flow contour plot for the current simulation, choose *Mass Flow* from the *Post* menu. This is a contour plot of the mass flow data generated by Quick. Quick Post uses XM.DAT and YM.DAT as axis data and MFLOW*.DAT as the mass flow data.

- Menu Options

  Click the right mouse button to get a popup menu with various viewing preferences. The only viewing options currently included are line width and number of contour lines.

3.4.2.2 Matlab Post Processing

Although postprocessing capabilities are included in the current Windows interface, users can also can plot the data using Matlab (this is useful for users running the code on UNIX machines for which there is no bundled post-processing). For example, to see a 3-D pressure plot, using **press01.dat,** use these Matlab commands:

```
load x.dat
load y.dat
load press01.dat
mesh(x, y, press01)
```

To see the averaged mass flow in **mflow01.dat**, issue the following Matlab commands:

```
load xm.dat
load ym.dat
load mflow01.dat
contour(xm, ym, mflow01, 100)
```

Matlab will plot 100 equal-increment stream lines for mass flow. However, no rail shapes are superimposed on the plot.

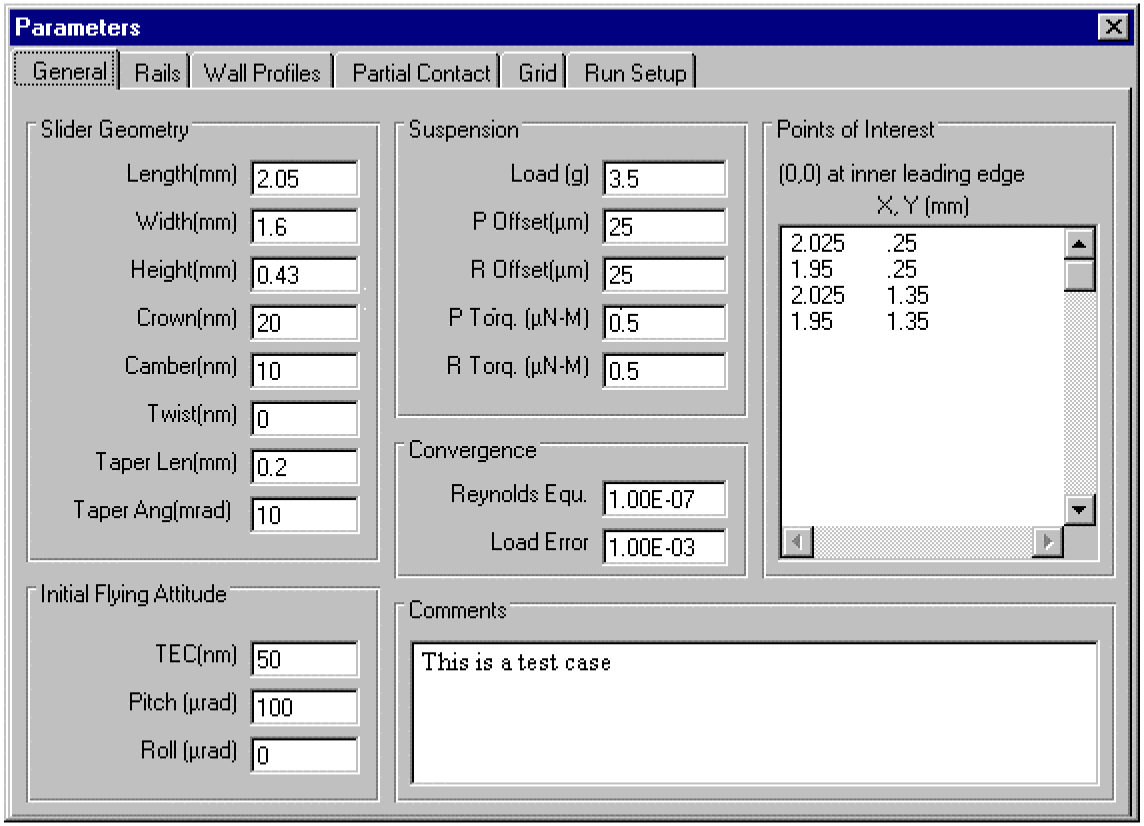
Parameters
General
Rails
Wall Profiles
Partial Contact
Grid
Run Setup
Slider Geometry
Length(mm) 2.05
Width(mm) 1.6
Height(mm) 0.43
Crown(nm) 20
Camber(nm) 10
Twist(nm) 0
Taper Len(mm) 0.2
Taper Ang(mrad) 10
Suspension
Load (g) 3.5
P Offset(µm) 25
R Offset(µm) 25
P Torq. (µN-M) 0.5
R Torq. (µN-M) 0.5
Convergence
Reynolds Equ. 1.00E-07
Load Error 1.00E-03
Points of Interest
(0,0) at inner leading edge
X, Y (mm)
2.025 .25
1.95 .25
2.025 1.35
1.95 1.35
Initial Flying Attitude
TEC(nm) 50
Pitch (µrad) 100
Roll (µrad) 0
Comments
This is a test case

Figure 1.

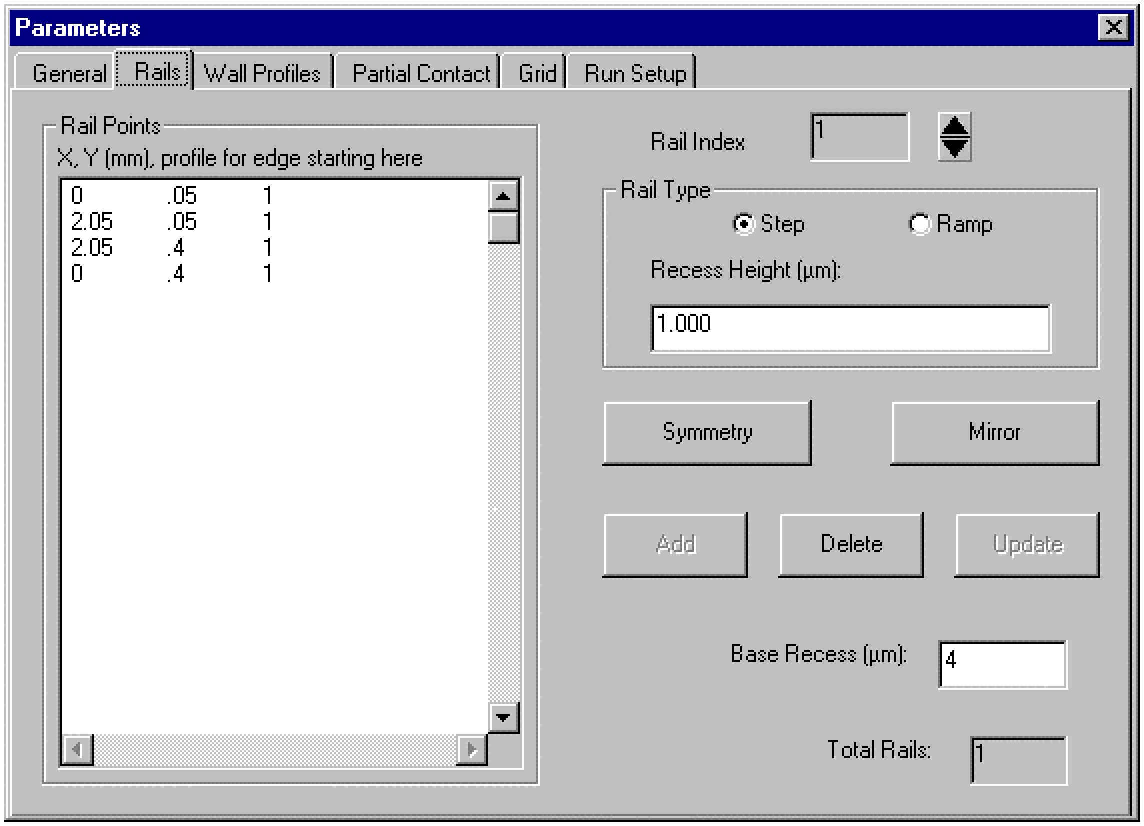
Parameters
General
Rails
Wall Profiles
Partial Contact
Grid
Run Setup
Rail Points
X, Y (mm), profile for edge starting here
0 .05 1
2.05 .05 1
2.05 .4 1
0 .4 1
Rail Index
1
Rail Type
Step
Ramp
Recess Height (µm):
1.000
Symmetry
Mirror
Add
Delete
Update
Base Recess (µm):
4
Total Rails:
1

Figure 2.

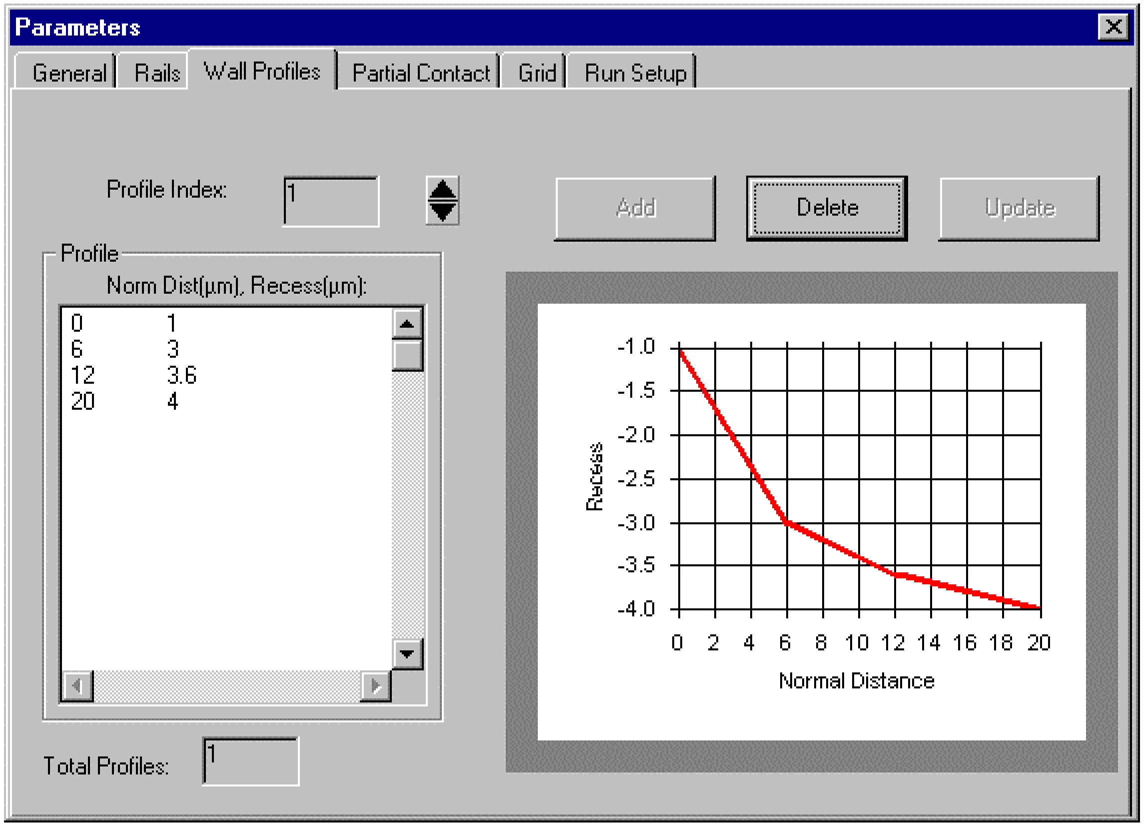
Parameters
General
Rails
Wall Profiles
Partial Contact
Grid
Run Setup
Profile Index:
1
Add
Delete
Update
Profile
Norm Dist(µm), Recess(µm):
0 1
6 3
12 3.6
20 4
Total Profiles:
1
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
Recess
0 2 4 6 8 10 12 14 16 18 20
Normal Distance

Figure 3.

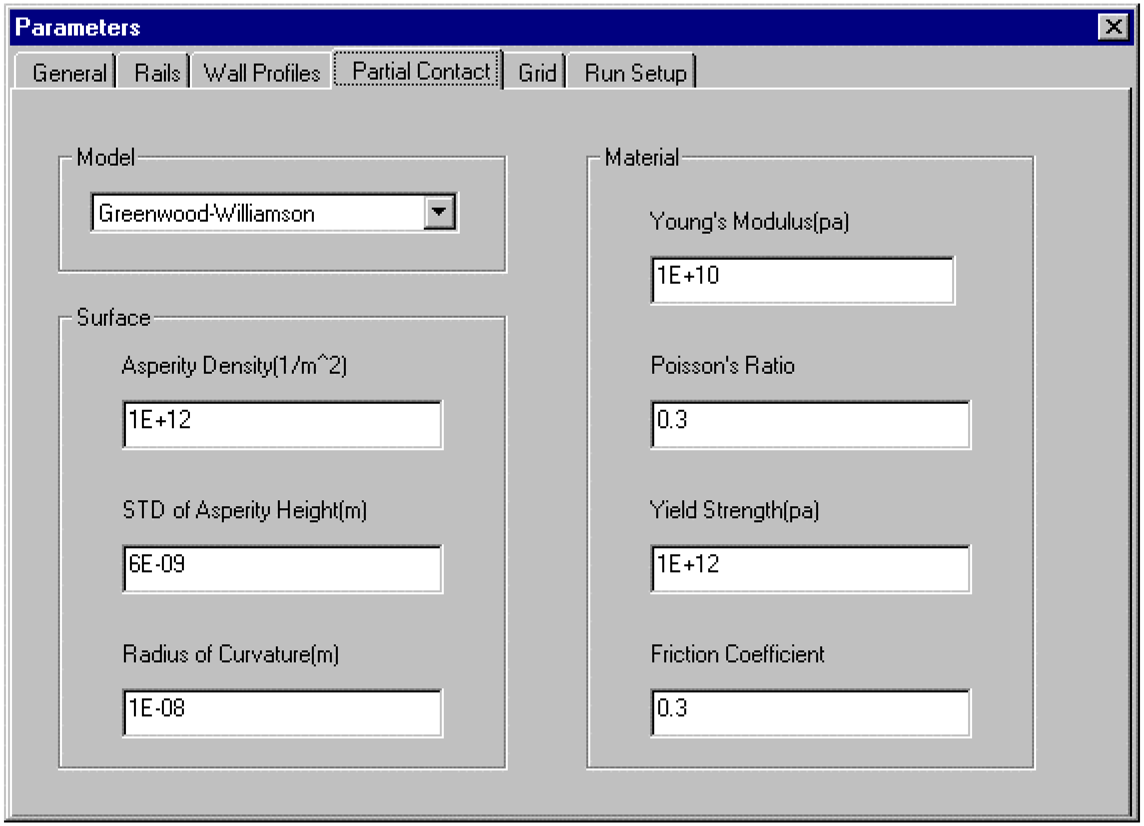
Parameters
General
Rails
Wall Profiles
Partial Contact
Grid
Run Setup
Model
Greenwood-Williamson
Surface
Asperity Density(1/m^2)
1E+12
STD of Asperity Height(m)
6E-09
Radius of Curvature(m)
1E-08
Material
Young's Modulus(pa)
1E+10
Poisson's Ratio
0.3
Yield Strength(pa)
1E+12
Friction Coefficient
0.3

Figure 4.

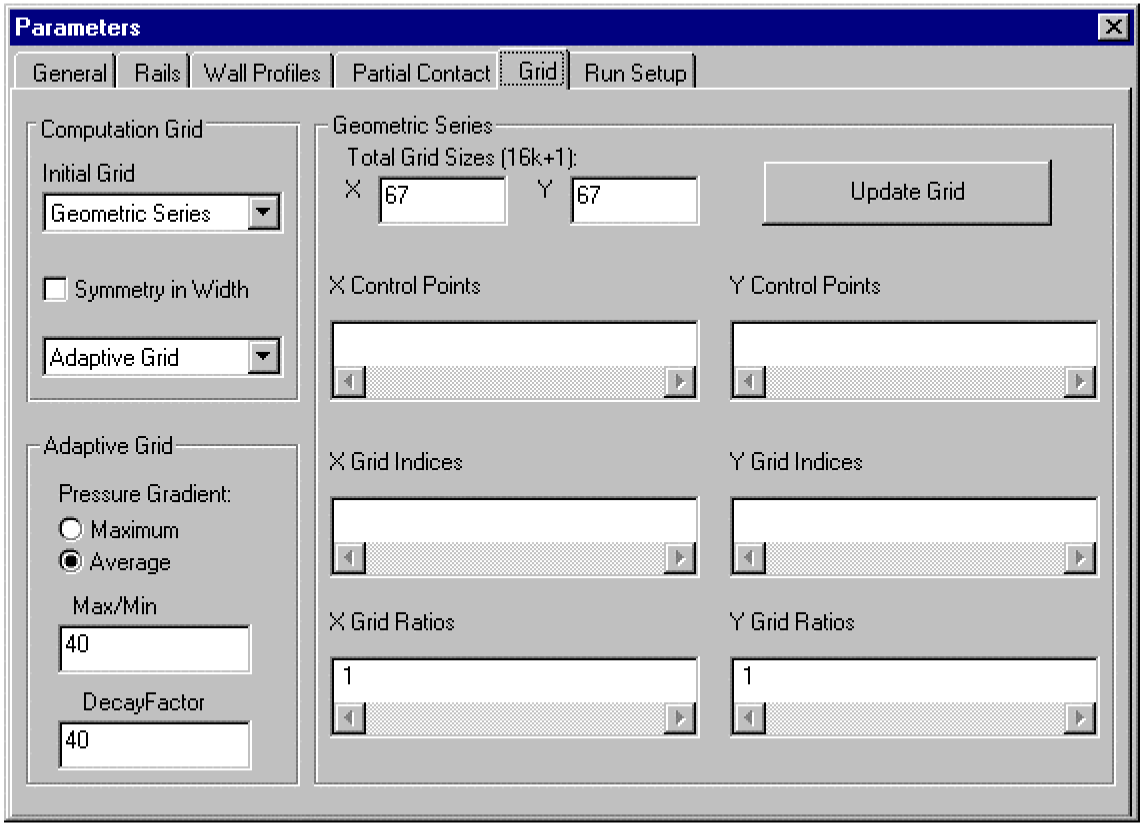
Parameters
General
Rails
Wall Profiles
Partial Contact
Grid
Run Setup
Computation Grid
Initial Grid
Geometric Series
Symmetry in Width
Adaptive Grid
Adaptive Grid
Pressure Gradient:
Maximum
Average
Max/Min
40
DecayFactor
40
Geometric Series
Total Grid Sizes (16k+1):
X
67
Y
67
Update Grid
X Control Points
Y Control Points
X Grid Indices
Y Grid Indices
X Grid Ratios
1
Y Grid Ratios
1

Figure 5.

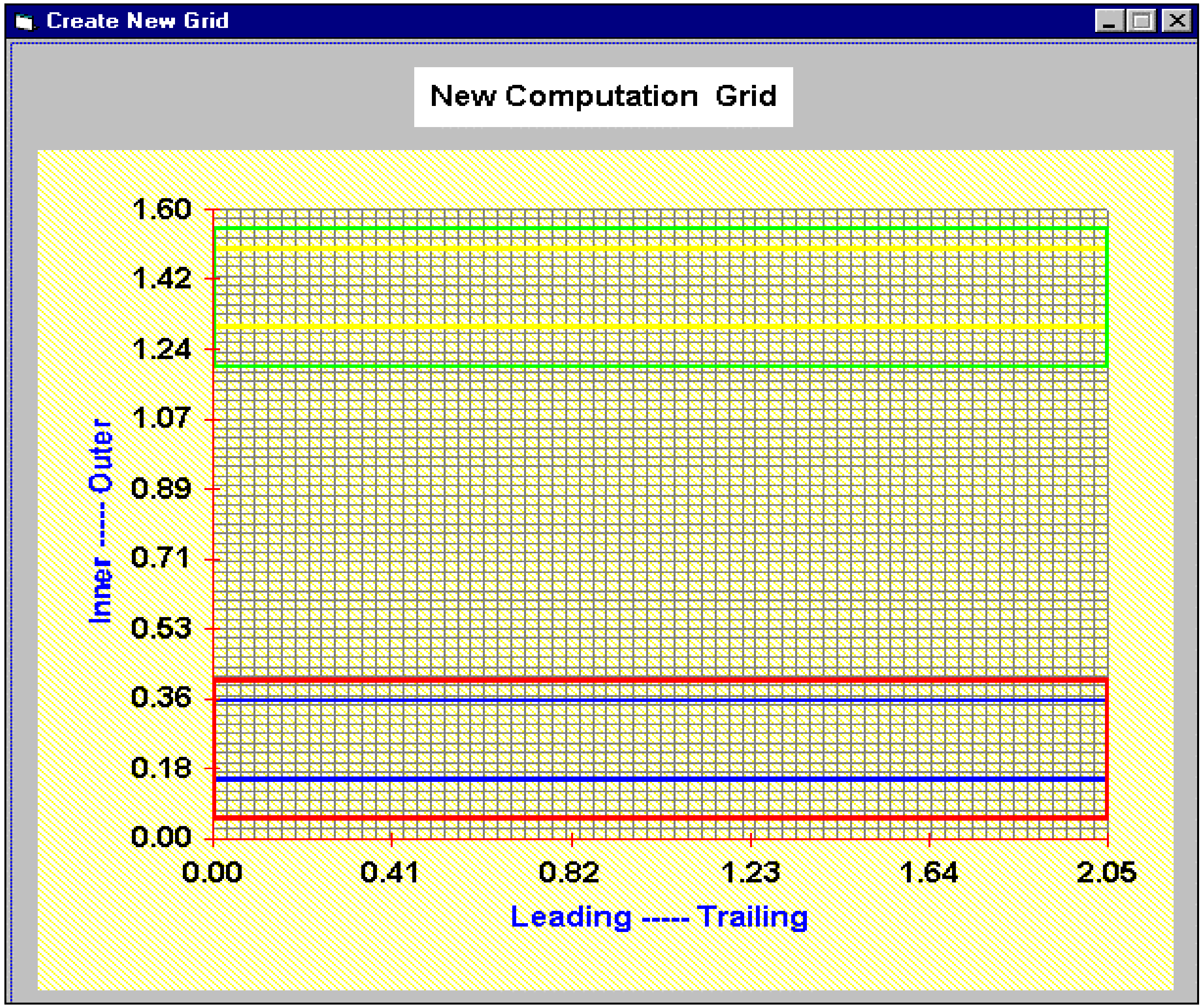
Create New Grid
New Computation Grid
1.60
1.42
1.24
1.07
0.89
0.71
0.53
0.36
0.18
0.00
Inner ----- Outer
0.00
0.41
0.82
1.23
1.64
2.05
Leading ----- Trailing

Figure 6.

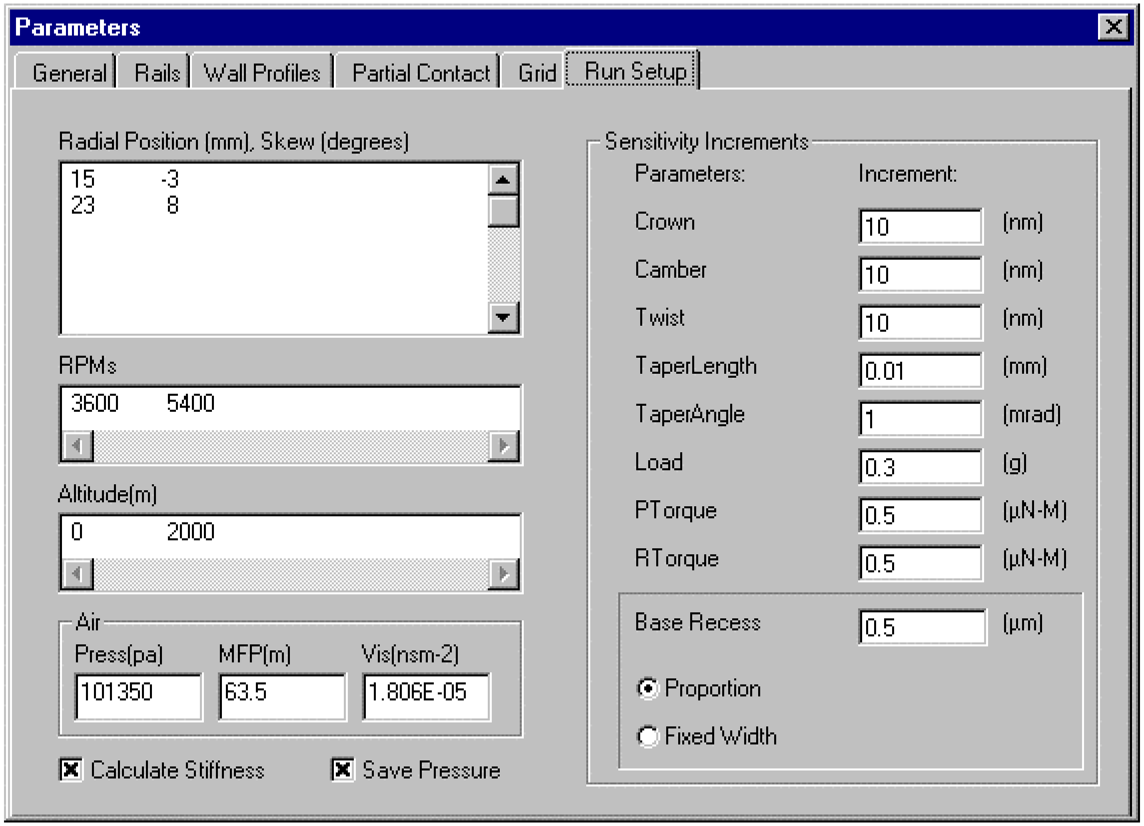
Parameters
General
Rails
Wall Profiles
Partial Contact
Grid
Run Setup
Radial Position (mm), Skew (degrees)
15 -3
23 8
RPMs
3600 5400
Altitude(m)
0 2000
Air
Press(pa)
MFP(m)
Vis(nsm-2)
101350
63.5
1.806E-05
Calculate Stiffness
Save Pressure
Sensitivity Increments
Parameters:
Increment:
Crown
10
(nm)
Camber
10
(nm)
Twist
10
(nm)
TaperLength
0.01
(mm)
TaperAngle
1
(mrad)
Load
0.3
(g)
PTorque
0.5
(μN-M)
RTorque
0.5
(μN-M)
Base Recess
0.5
(μm)
Proportion
Fixed Width

Figure 7

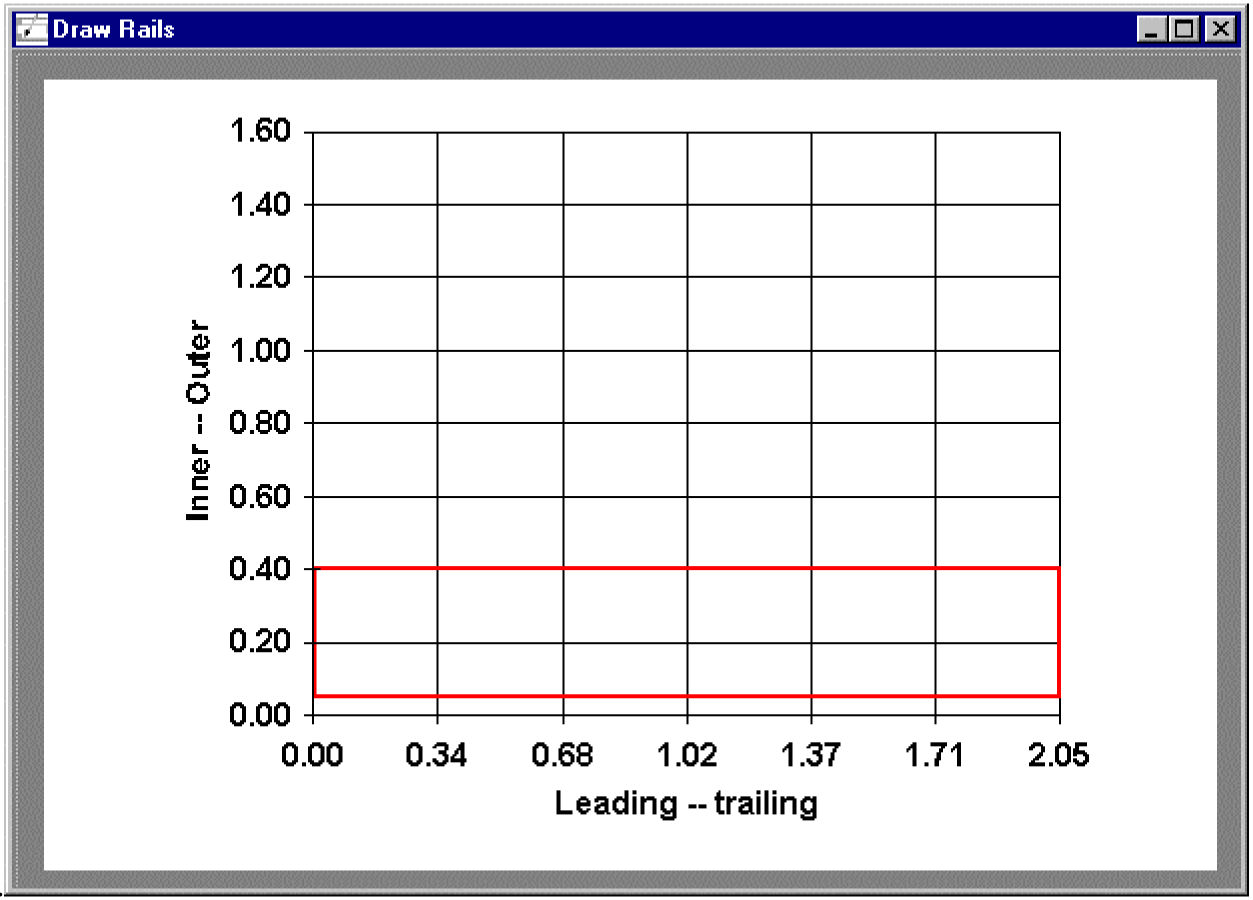
Draw Rails
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Inner -- Outer
0.00
0.34
0.68
1.02
1.37
1.71
2.05
Leading -- trailing

Figure 8.

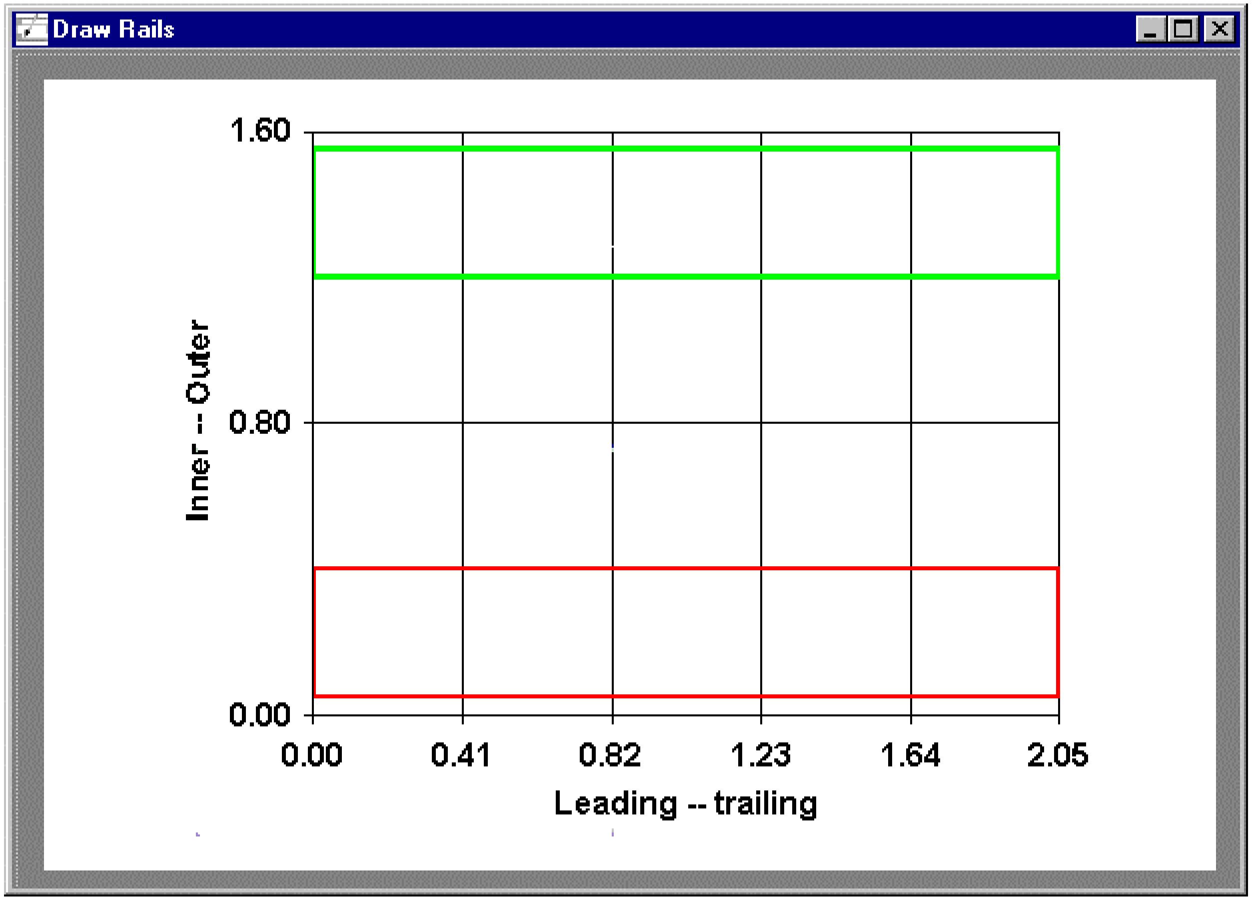
Draw Rails
1.60
0.80
0.00
Inner -- Outer
0.00
0.41
0.82
1.23
1.64
2.05
Leading -- trailing

Figure 9.

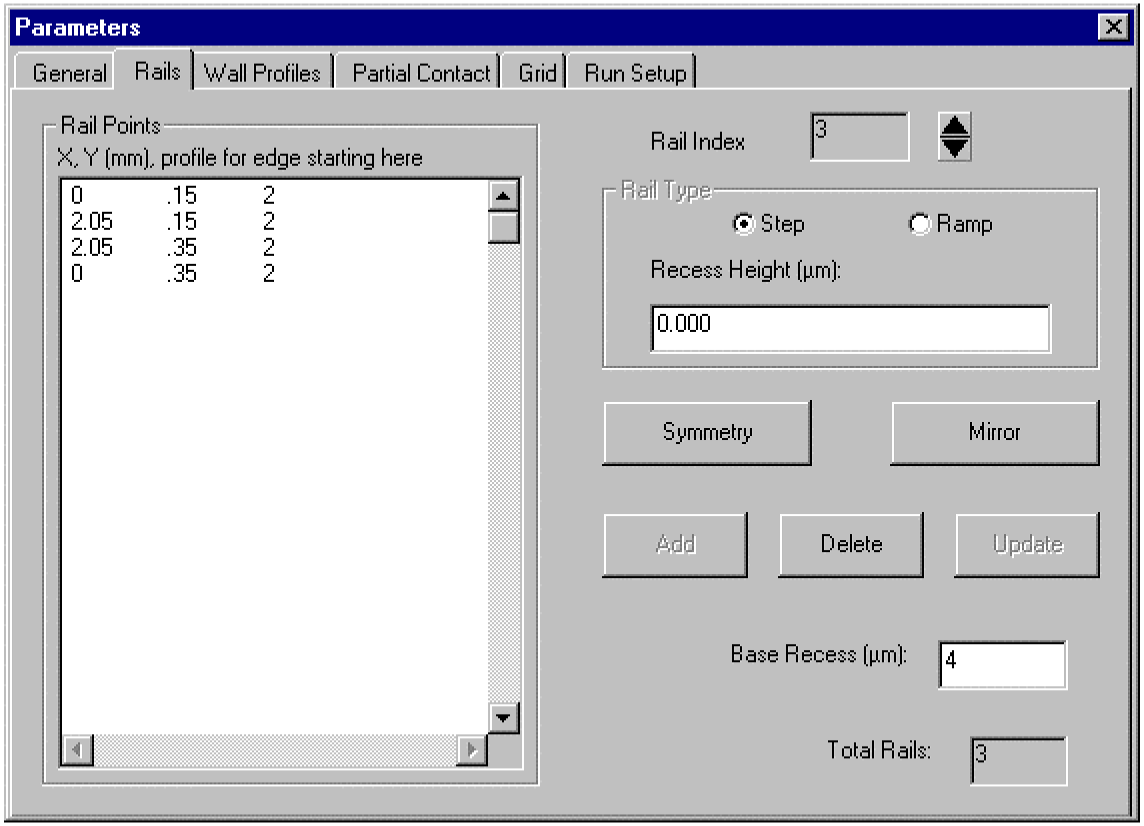
Parameters
General
Rails
Wall Profiles
Partial Contact
Grid
Run Setup
Rail Points
X, Y (mm), profile for edge starting here
0 .15 2
2.05 .15 2
2.05 .35 2
0 .35 2
Rail Index
3
Rail Type
Step
Ramp
Recess Height (µm):
0.000
Symmetry
Mirror
Add
Delete
Update
Base Recess (µm):
4
Total Rails:
3

Figure 10.

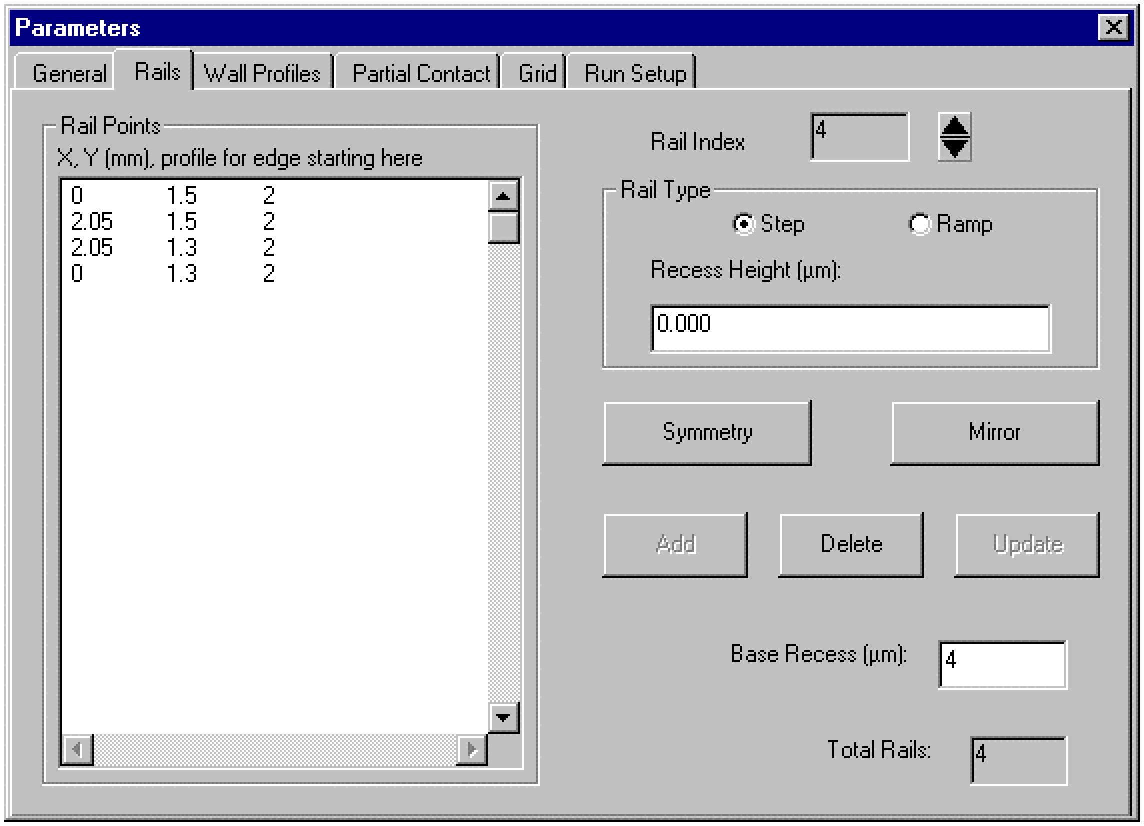
Parameters
General
Rails
Wall Profiles
Partial Contact
Grid
Run Setup
Rail Points
X, Y (mm), profile for edge starting here
0 1.5 2
2.05 1.5 2
2.05 1.3 2
0 1.3 2
Rail Index
4
Rail Type
Step
Ramp
Recess Height (µm):
0.000
Symmetry
Mirror
Add
Delete
Update
Base Recess (µm):
4
Total Rails:
4

Figure 11.

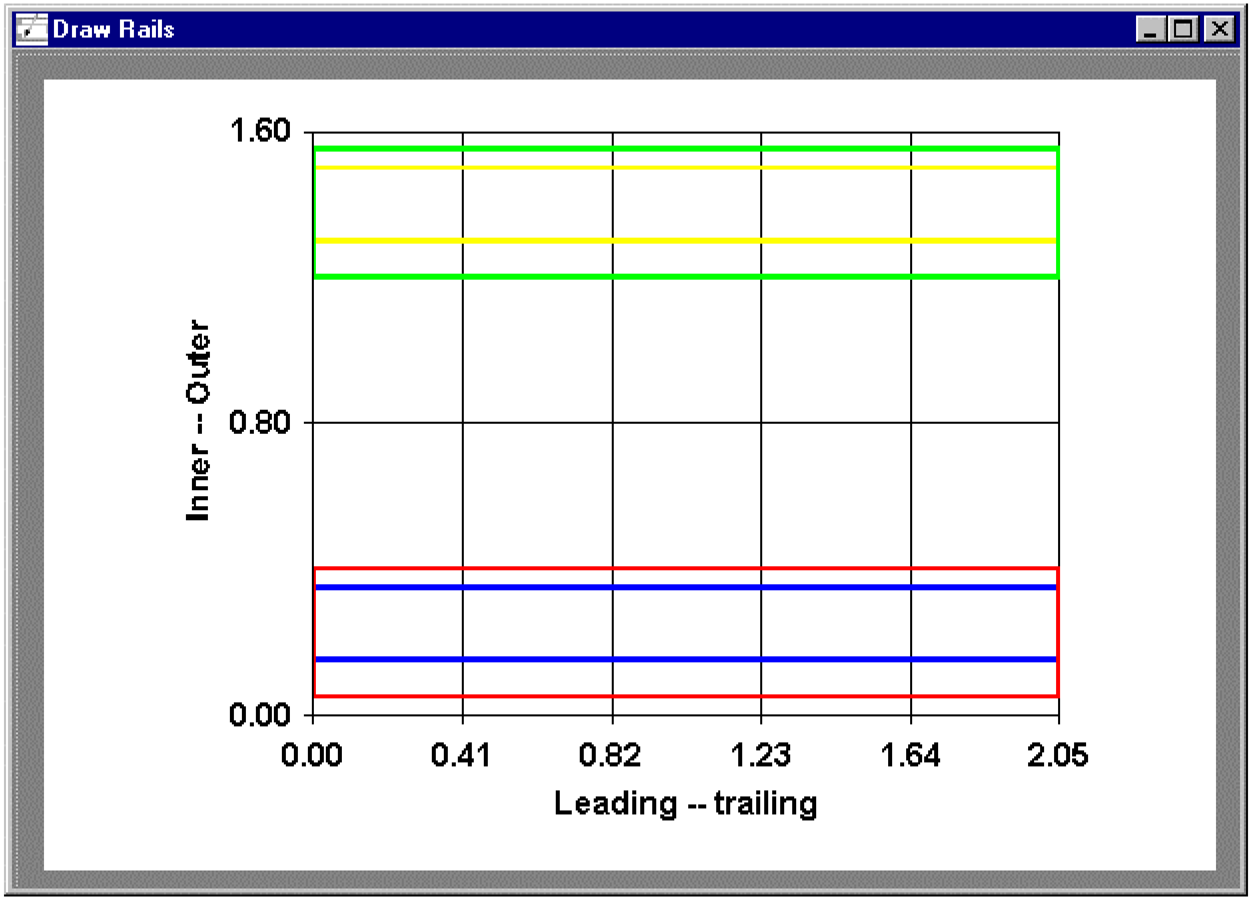
Draw Rails
1.60
0.80
0.00
Inner -- Outer
0.00
0.41
0.82
1.23
1.64
2.05
Leading -- trailing

Figure 12.

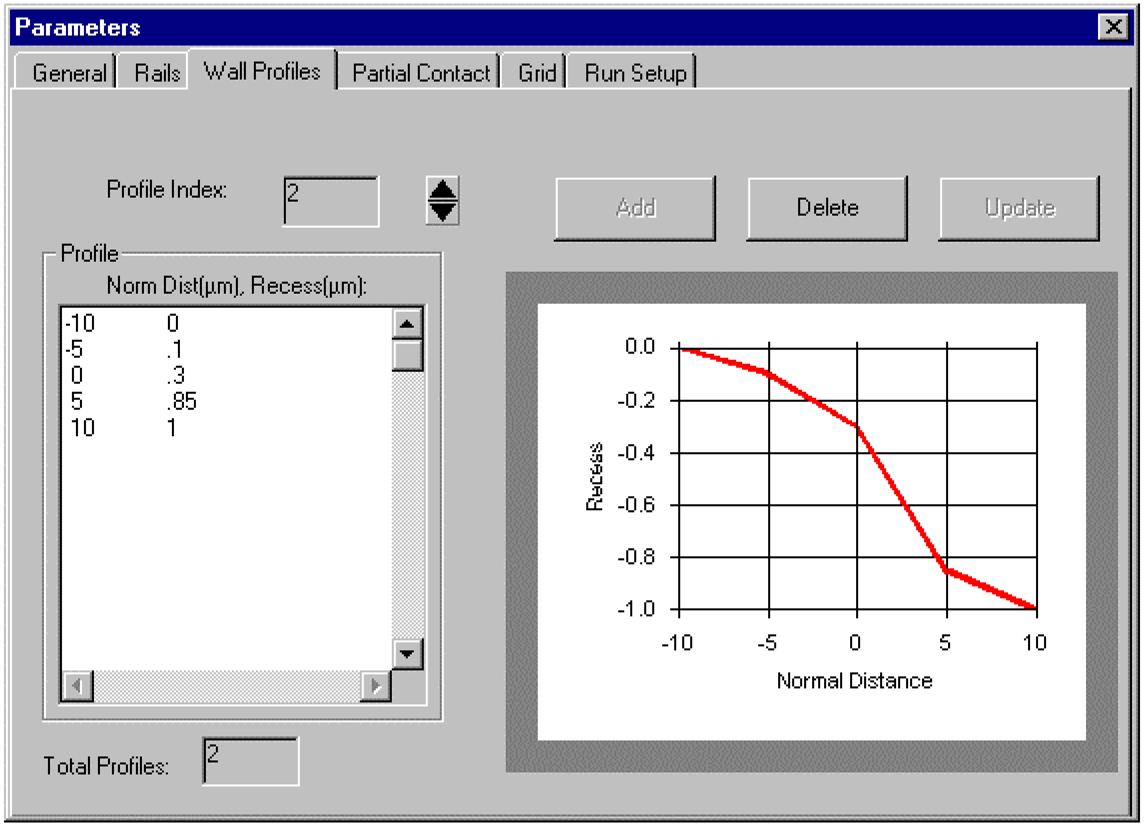
Parameters
General
Rails
Wall Profiles
Partial Contact
Grid
Run Setup
Profile Index:
2
Add
Delete
Update
Profile
Norm Dist(µm), Recess(µm):
-10 0
-5 .1
0 .3
5 .85
10 1
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
Recess
-10
-5
0
5
10
Normal Distance
Total Profiles:
2

Figure 13.