Hybrid Gradient Adaptive Mesh with Refinement Features for Ultra Low Flying Height Sliders

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ABSTRACT

For 1Tbit/in2 areal density magnetic storage disk drives, the minimum flying height of the air bearing sliders is less than 5nm. At such low fly heights, very high air pressure and pressure gradients are introduced at certain locations in the air bearing. Also, one needs to consider intermolecular forces between the slider and disk surfaces for such nanoscale spacing. To successfully simulate such complex air bearing designs, a robust mesh covering detailed features is required. In this paper, a hybrid adaptive mesh with refining ability is proposed and used on an example complex design. The mesh refinement feature allows users to control the grid density at desired locations, such as the minimum spacing locations, discontinuities, and the front taper. The results show that the new mesh method not only can resolve very high pressure and pressure gradient regions of ultra-low flying height sliders, but also it is more robust than the previous adaptive mesh used in the rectangular code (Quick 4) of the CML air bearing design program.

1. Introduction

The CML air bearing design code with its pressure gradient adaptive mesh has been successfully used for more than 15 years to design air bearing sliders for hard disk drives. For future magnetic disk drives, the data density is expected to be as large as 1 Tbit/in2. For such high bit density, the minimum flying height of sliders is less than 5nm. At such extremely low spacing, very high air pressure is observed in most designs. Also, for such applications the sliders become more and more complex in geometry. The design of future slider air bearings depends on a successful numerical solution, which requires a robust and adequate grid generation algorithm used in solving the generalized Reynolds equation. There are two types of grids suitable for complex air bearing designs. One is a rectangular mesh which is employed in the CML Quick 4 solver [1, 2]. The other one employs a triangular meshing method, Quick 5, which was introduced recently in the CML code by Wu and Bogy [3]. Their unstructured adaptive triangular mesh technique is usually very efficient for traditional slider designs without small landing pads. However, sometimes it is difficult to mesh very complex designs using Quick 5. Also, there are presently no refinement features available in the rectangular or triangular grid generation methods used in the air bearing design codes. For current ultra-low flying height slider designs, there are pads and grooves to meet various requirements. Also, the minimum spacing will become less than 5nm in the near future. In this case the pressure at the minimum spacing is extremely high due to the air squeezing effect, which requires a very fine mesh at this location. When the spacing between the slider and disk surfaces is less than 5nm, the intermolecular force between the slider air bearing and disk surface should be included in the calculation. The mesh used to calculate the intermolecular forces should be fine enough to yield a converged result.

In this paper, a meshing method with refinement features based on a combination of geometric and pressure gradients is proposed. The mesh refinement feature allows users to control the grid density at desired locations, such as minimum spacing locations, discontinuities along rails, and at the front taper. The results show that the new meshing method not only can resolve very high pressure and pressure gradient regions of ultra-low flying height sliders, but it also is more robust and converges more rapidly with increasing mesh numbers than the pressure adaptive mesh used in Quick 4. It is also less dependent on the initial conditions chosen for calculation, and it requires less computation time.

2. Grid Generated by Geometric Progression

For solving the Reynold's equation with the CML rectangular mesh, the grid is initially generated by geometric progression in both the x and y directions. The computational domain can be divided into several intervals. For each interval, the control points can be specified by user input. Also, an expansion ratio for each interval can be assigned. The grid number becomes larger if the expansion ratio is greater than unity. For symmetric sliders, one may mesh only half of the slider in the computational domain. The other half will be mirrored automatically. Typically, one uses a uniform grid as the basis for mesh adaptation.

3. Adaptive Grid with Refinement Features

Due to the complexity of modern air bearing designs uniform meshing is usually not adequate. The air bearing contains geometric discontinuities and wall profiles that are produced by etching processes. Also, there are certain locations that have extremely high air pressure and pressure gradients due to the air squeezing effect. Generally, more grids are needed at such locations. An adaptive grid with refinement features not only can provide more grids at these locations, but it can also decrease the total grid number for the whole computational domain. Therefore, it reduces the requirement on computational resources and shortens the slider design process. Previously, pressure gradients were used to adapt the grid distribution in both the x and y directions. This approach can resolve certain high pressure and pressure gradient locations. However, this approach often does not perform very well at geometric discontinuities where geometric gradients should be used to replace pressure gradients as the grid density function. To avoid extremely high pressures or geometric gradients, an allowable ratio of maximum to minimum gradients is specified in the program, and it can be changed by user input.

Relatively small features such as landing pads designed to avoid meniscus force effects when the slider lands on the disk are used in complex slider designs, and they are not covered well by the previous meshing methods. For these features, local mesh refinement is required. The level of mesh refinement can be specified by user input.

4. Grid Snapping and Smoothing

It has been shown by Lu and Bogy [1] that grid snapping is very effective for achieving a stable convergence to the final flying height. Without grid snapping, large fluctuations of the flying height and roll are evident as the computation progresses. Grid snapping is most effective for rails with straight boundaries. And also, it is required that the grid lines should align to the taper end if there is a taper in the air bearing design.

For numerical simulations, abrupt changes in the grid size cause numerical errors. To reduce these numerical errors, smoothing techniques are employed. In the current implementation, an exponentially decaying function is used. One may specify how fast the grid size changes by giving a certain decay factor. A larger decay factor means less grid smoothing. However, a very small decay factor also causes problems because the grids are too densely focused at one location. Usually, a decay factor of about 60 is recommended for air bearing designs.

In order to incorporate the hybrid gradient adaptive meshing method with refinement features we needed to change the Quick 4 input file. The example input file is given in Appendix I which shows the new parameters in bold text. The input file not only lets the user control the meshing in the grid in x and y directions separately, it also lets the user refine the mesh at any location with a desired level. For the intermolecular force study the Hamaker constants can also be input in the intermolecular force menu.

To generate an appropriate grid mesh for a complex air bearing with an ultra low flying height, one may iterate the grid meshing process to get stable and reliable flying characteristics.

5. Numerical Results and Discussions

To study the effect of the current hybrid gradient adaptive meshing method, we chose an example slider which is shown in Figure 1. This slider had been designed with the old code to run at 3.5 nm at the radius of 17mm with a skew angle of 1.1 degrees. In our previous study, it was found that the simulated flying height increased with an increase of the grid size, and it was difficult to get a convergent flying height for this complex air bearing design using the pressure gradient meshing grids. The grid generated by that method is shown in Figure 2. One can see from Figure 2 that although the grid in the y direction is very concentrated in the middle of the slider, the mesh in x direction is less concentrated at the trailing pad. For such an ultra low flying height air bearing design, the pressure at the center of the trailing pad is more than 25atm as shown in Figure 3. The grid mesh does not capture this pressure spike very well. Also, in this complex air bearing design, there are several geometrically steep step edges. Typically, none of these transition regions is covered by enough grids. To improve the mesh at these steep transitions we used the hybrid gradient mesh as shown in Figure 4 where the geometric gradient controlled the grid density in the x direction and the pressure gradient controlled the grid density in the y direction. Figure 5 shows the pressure profile obtained with this mesh. While no major changes are observed, the pressure profile is actually smoother than the one in Figure 3 due to the finer mesh in the steep geometric regions. Figure 6 shows the comparison of the nominal flying height calculated by these two meshes at different grid sizes. The nominal flying height increases with the grid size and does not appear to converge for the pressure gradient adaptive mesh. However, the nominal flying height clearly shows convergence at a grid size of 705 when the hybrid gradient meshing grid is employed.

For some applications, mesh refinement is also desirable. In this new mesh generation method, this feature is also enabled. Figure 7 shows the mesh generated by the hybrid gradient with 4X refinement at the minimum spacing of the slider. The pressure profile calculated by this mesh is shown in Figure 8. This pressure profile is very similar to that of Figure 5. The effect of mesh refinement on the nominal flying height is shown in Figure 9. The mesh size used for this calculation is 593. One can see that mesh refinement can improve the convergence of the nominal flying height. The nominal flying height becomes steady after the 4X mesh refinement is applied at the minimum spacing location. Figure 10 shows that the nominal flying height converges with grid size using this refined mesh. Even at the grid size of 593, the nominal flying height reaches its converged value. With this new mesh the calculation time is usually less than that with the pressure gradient mesh.

For ultra low flying height sliders, one needs to also consider intermolecular forces between the slider and disk surfaces. The intermolecular forces are largest at the minimum spacing between the slider air bearing and disk surface, which requires enough grids to precisely cover this region. Figure 11 shows the mesh refinement effect on the intermolecular force calculation. In this calculation, the nominal flying height is fixed at 3.745nm with a pitch angle of 119 μrad and a roll angle of 1.825 μrad. The total intermolecular force decreases with an increase of grid size since the molecular force is very sensitive to the local height. At the refinement level of 40, the intermolecular force becomes converged at 0.133 gram.

Figure 12 show the convergence process comparison between the old pressure gradient adaptive grid and the new hybrid gradient grid, and the comparison with and without molecular force for this example slider. The grid size is set to 593 for all these cases. The initial flying height is 6nm with a pitch angle of 150 μrad and a roll angle of 5 μrad. Figure 12 also shows that the hybrid gradient grid converges faster than the pressure gradient. Also, with the effect of intermolecular force included, the convergence process becomes slower. The intermolecular force causes the slider to fly lower with a nominal flying height of 3.732 nm.

6. Conclusions

In this paper a hybrid adaptive mesh with refining ability is proposed and used on an ultra low flying height complex design. The mesh refinement feature allows users to control the grid density at desired locations, such as the minimum spacing locations, geometric discontinuities along rails, and at the front taper. The results show that this new hybrid gradient adaptive mesh method not only can resolve very high pressure and pressure gradient regions for ultra-low flying height sliders, but it is also more robust and quicker to converge than the pressure gradient adaptive grid used in Quick 4. Mesh refinement is also required for the intermolecular force calculation between a slider air bearing and disk surface because it is very sensitive to spacing and grid size.

Acknowledgements

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References

[1] Lu, S., 1997, Numerical Simulation of Slider Air Bearings, Doctoral Dissertation, Department of Mechanical Engineering, University of California, Berkeley.

[2] Lu, S., Grisso, R. and Bogy, D. B., 1996, CML Air Bearing Design Program User's Manual (Version 4), CML Technical Report 96-9619, Computer Mechanics Laboratory, Department of Mechanical Engineering, University of California, Berkeley.

[3] Wu, L., 2001, Physical Modeling and Numerical Simulations of the Slider Air Bearing Problem of Hard, Doctoral Dissertation, Department of Mechanical Engineering, University of California, Berkeley.

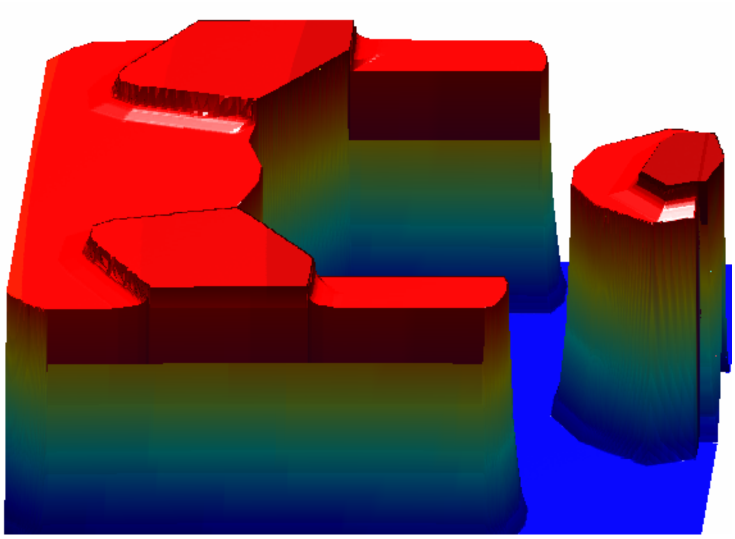

Figure 1. An example slider for studying the hybrid adaptive meshing grid.

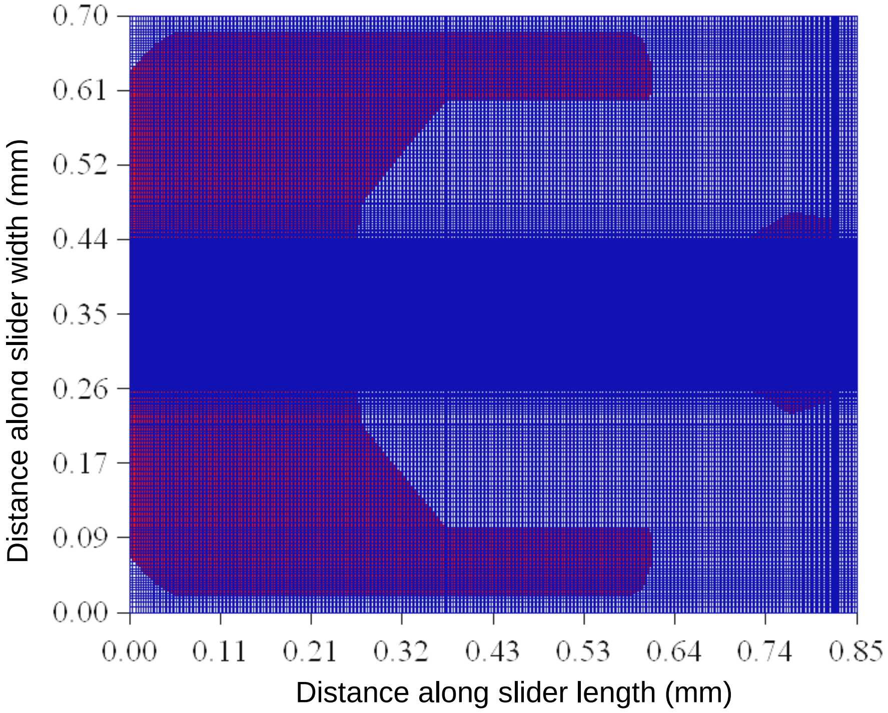

Figure 2. Pressure gradient adaptive mesh grids for the example slider.

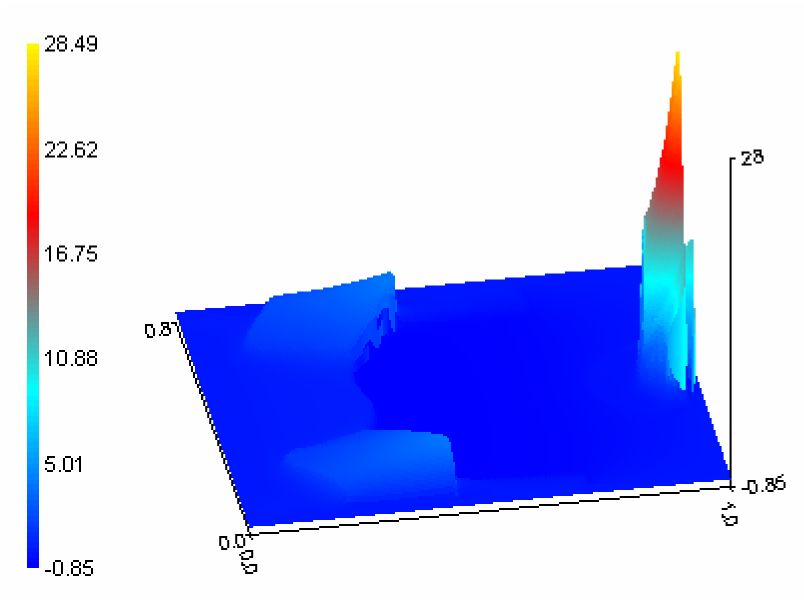

Figure 3. Pressure profile calculated by pressure gradient adaptive mesh.

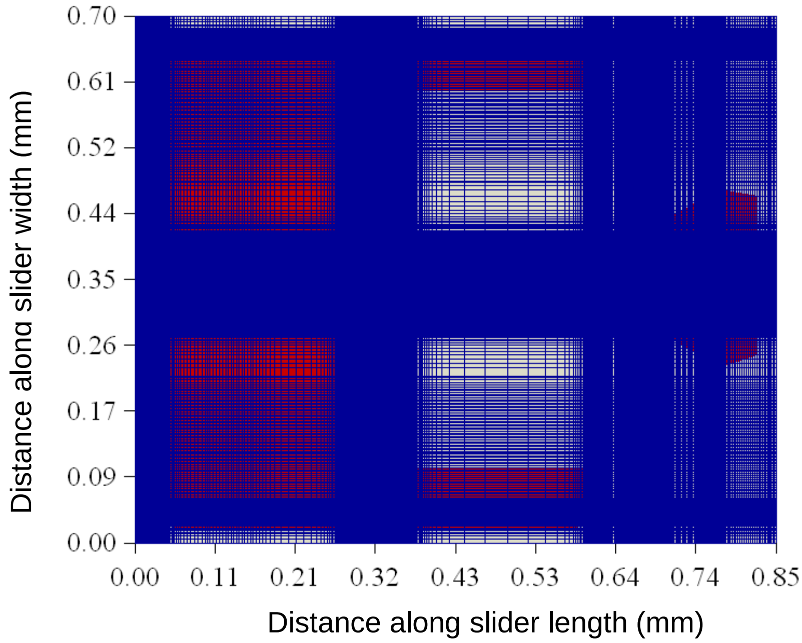

Figure 4. Hybrid gradient adaptive mesh grids without refinement features.

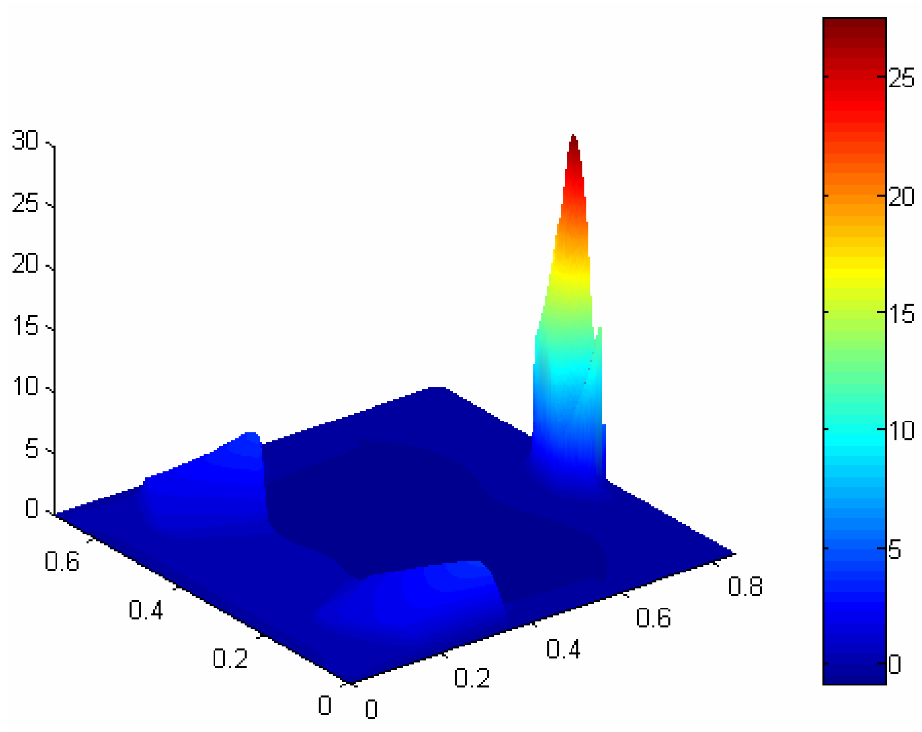

Figure 5. Pressure profile calculated by hybrid gradient adaptive mesh grids.

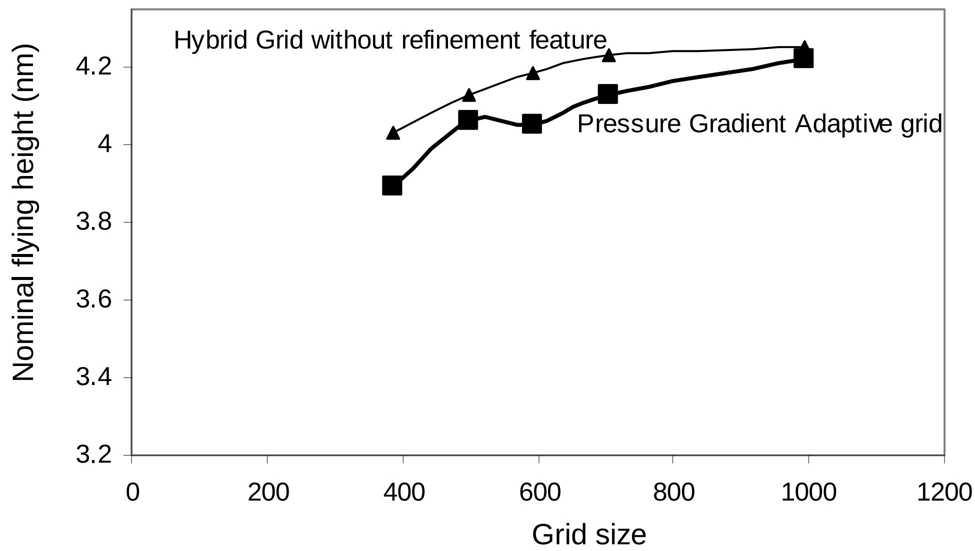

Figure 6. Flying height comparison between pressure gradient and hybrid grids.

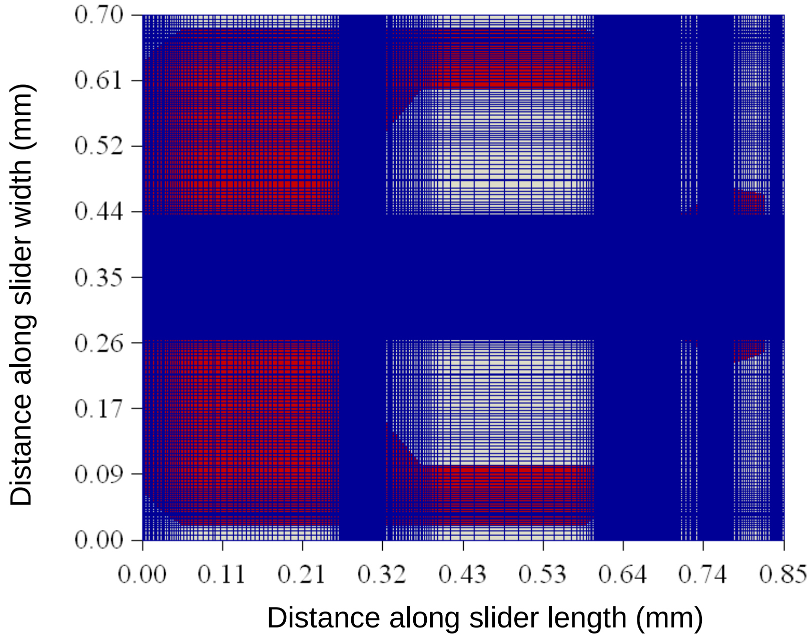

Figure 7. Hybrid gradient adaptive mesh with 4X refinement grids.

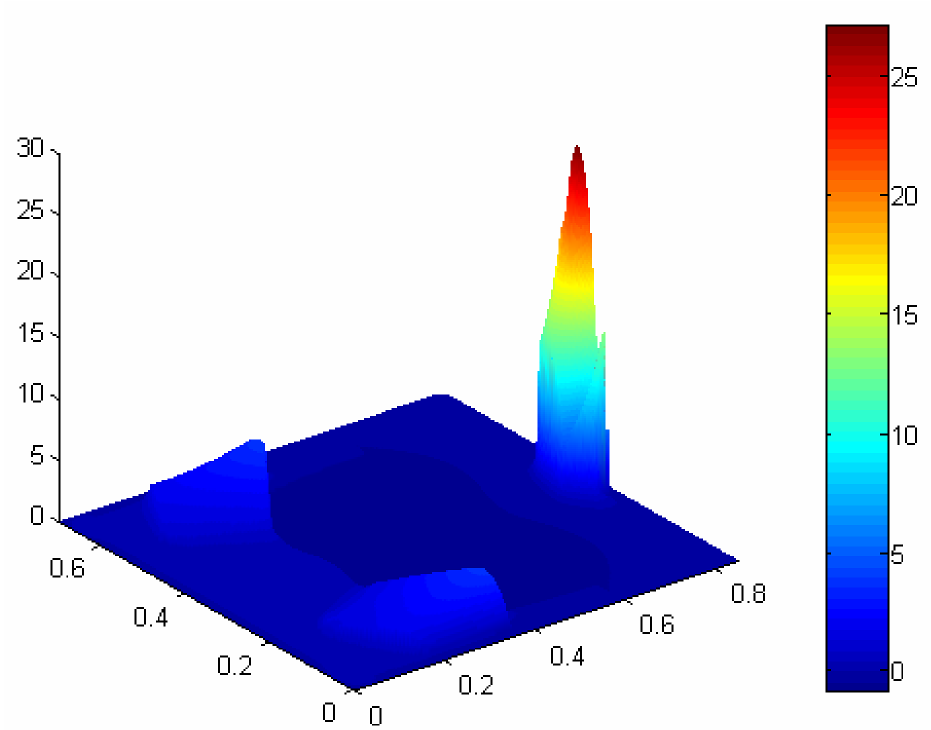

Figure 8. Pressure profile calculated by hybrid adaptive grids with 4X refinement.

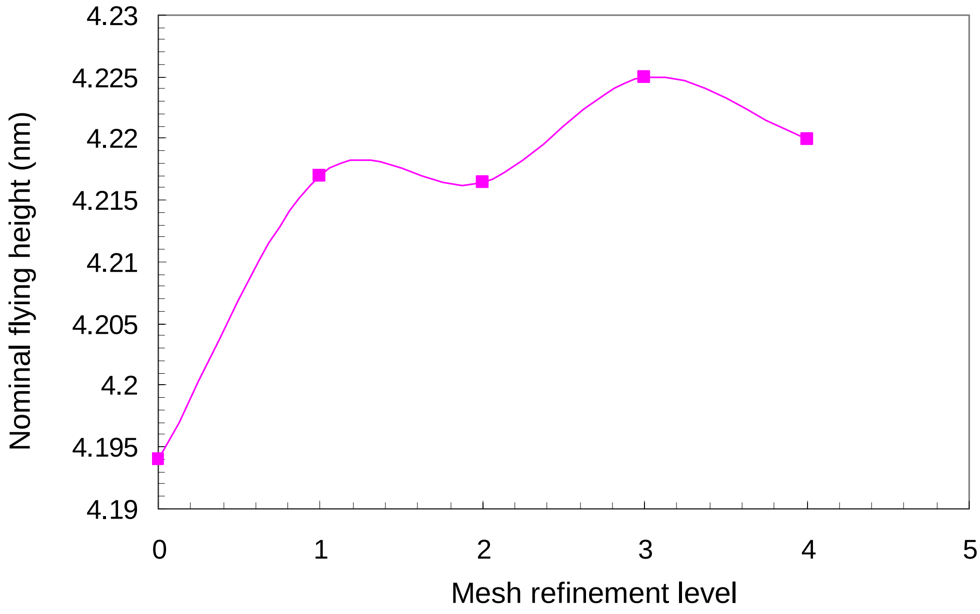

Figure 9. Effect of mesh refinement level on flying height convergence.

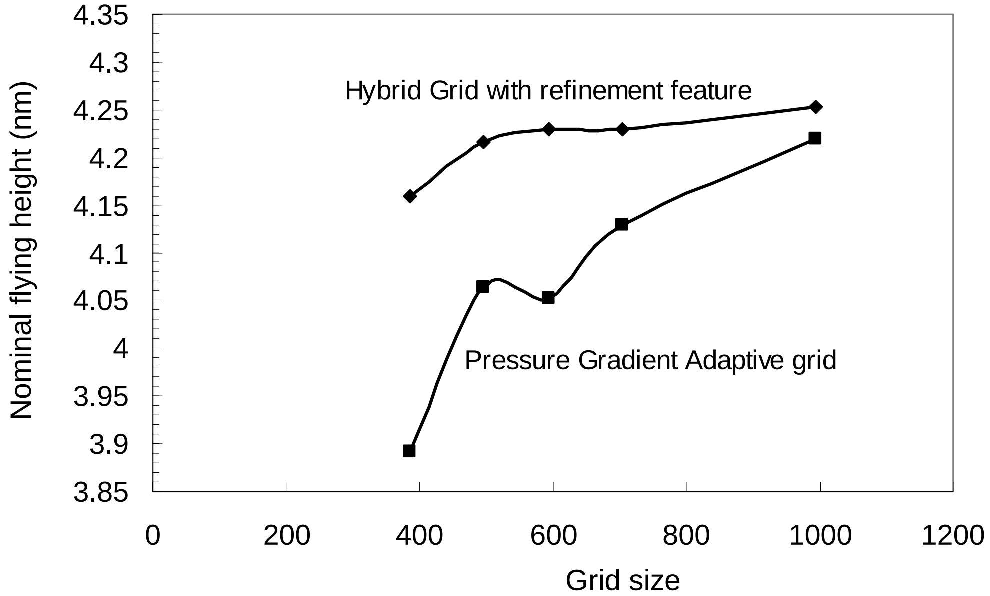

Figure 10. Effect of grid refinement on flying height convergence.

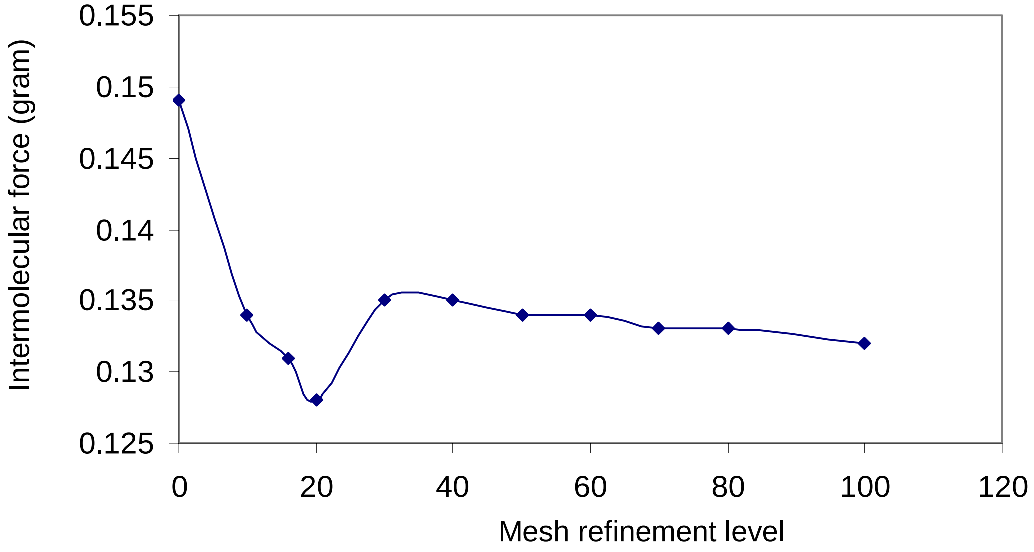

Figure 11. Effect of grid meshing on intermolecular forces between the slider and disk.

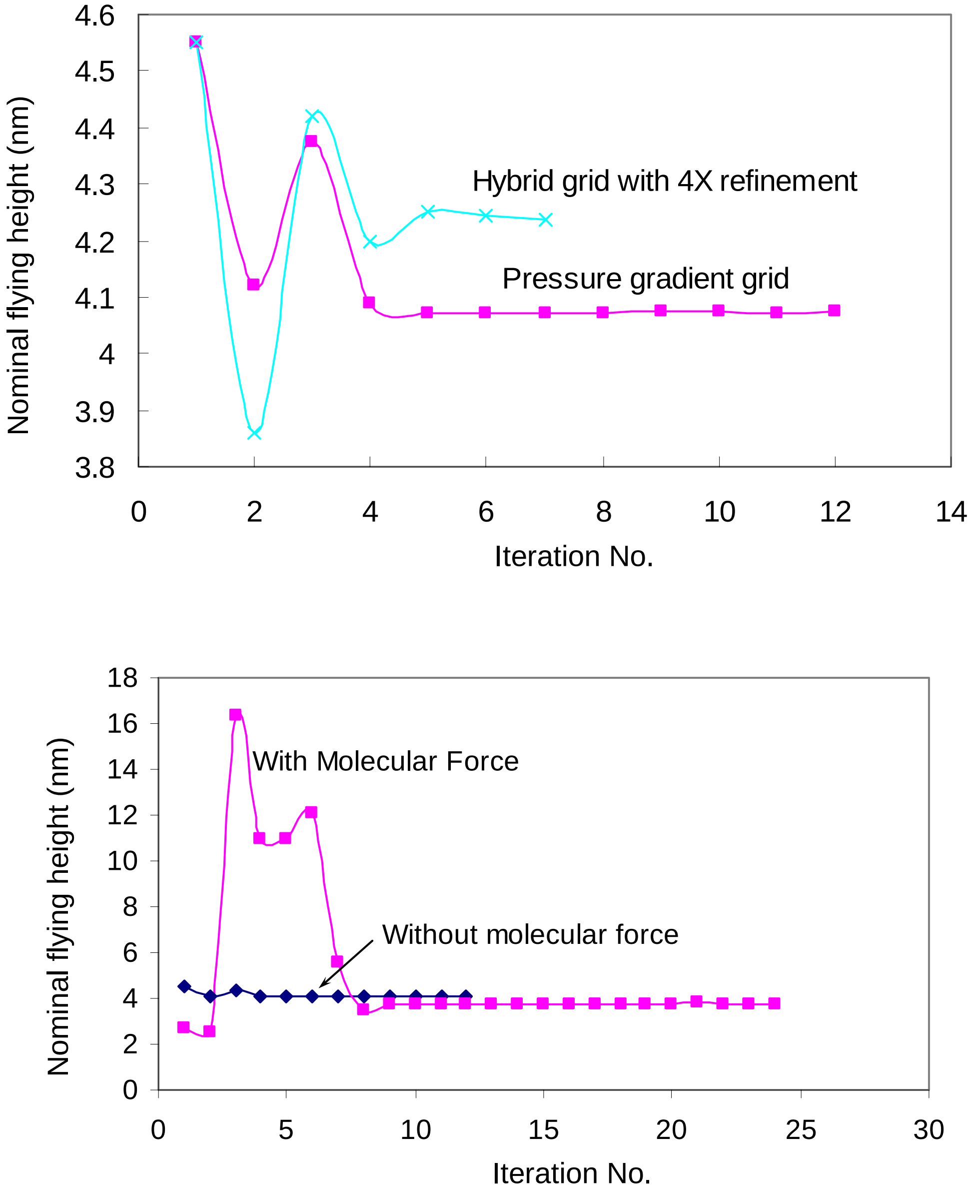

Figure 12. Effect of initial conditions on flying height on ultra low flying height sliders.

Appendix I: Modified Quick 4 RUN.DAT

```
CML Version 4.019  RUN.DAT
REPORT BUGS TO INFO@CML.ME.BERKELEY.EDU
***************Solution Control***************
istiff isolv   ioldg   iadpt   isave
 1      1       0       1       1
***************Intial Attitude***************
hm(m)          pitch(rad)     roll(rad)
4.4380E-009    1.6310E-004    1.8330E-006
***************Runs***************
irad           irpm           ialt
 1             1              0
radii(m)
  1.7100E-002
skews(deg)
  1.1000E+000
RPMs
  1.0000E+004
altitudes(m)

***************Air Parameters***************
p0(pa)         al(m)          vis(nsm^-2)
1.0135E+005    6.3500E-008    1.8060E-005
***************Load Parameters***************
f0(kg)         xf0(m)         yf0(m)
1.5000E-003    0.0000E+000    0.0000E+000
xfs(µNM)       yfs(µNM)       emax
0.0000E+000    0.0000E+000    1.0000E-004
***************Grid Control***************
nx      ny
 593     593
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
100            60             0
40             60             0
```

******************Mesh refinement in x direction*********
1
0.805e-3 0.845e-3 4
******************mesh refinement in y direction*********
1
0.375e-3 0.415e-3 4

```
***************Reynolds Equation***************
ischeme      imdoel      akmax      beta      gamma
 2           3           1.0000E-007   6.0000E+000   6.0000E+000
***************Partial Contact***************
icmodel      stdasp(m)     dnsasp(m^-2)   ConstantA     ConstantB
 0           6.0000E-009   1.0000E+012   1.0000E-019   0.0000E+000
rdsasp(m)     eyoung(pa)    yldstr(pa)
1.0000E-008   3.4000E+011   2.0000E+008
frcoe        pratio
 0.2         0.3
```

*****************Molecular Force Hamaker Constants(ahc,bhc)*******
1.0e-19 1.0e-76

```
***************Sensitivities***************
crowninc(m)    camberinc(m)   twistinc(m)
0.0000E+000   0.0000E+000   0.0000E+000
tlnginc(m)     tanginc(rad)   loadinc(kg)
0.0000E+000   0.0000E+000   0.0000E+000
ptrqinc(µNM)   rtrquinc(µNM)  recessinc(m)
0.0000E+000   0.0000E+000   0.0000E+000
iwscale
 1
***************Comments***************
"This is a test case"
```