The CML Air Bearing Dynamic Simulator

Version 4.21

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October 1997

1 Introduction

This report is an updated manual for the air bearing dynamic simulator developed at the Computer Mechanics Laboratory at the University of California at Berkeley. It is based on a previous CML technical report (Hu, Y. and Bogy, D. B. 1995).

The code described in this report provides the numerical analysis of head-suspension assembly dynamics for shaped-rail sliders. The program simultaneously solves the generalized Reynolds equation and the equations of motion of the head-suspension assembly. The slider's motion is determined by the balance of the air bearing pressure, the suspension force, the contact forces and the inertia. The suspension force can be represented using either the flexure stiffness and damping coefficients or the suspension dynamics. As an alternative to the finite element solution for the suspension, a modal truncation method is used to include the contribution of the suspension assembly dynamics in the dynamic analysis. The suspension assembly equations of motion are transformed into modal coordinates. The method is very effective in reducing the dimensions of the numerical scheme for solving the equations of motion while retaining essential dynamic characteristics of the problem.

The time-dependent nonlinear generalized Reynolds equation is directly discretized using Patankar's control volume method. The final discretization equations are solved using the alternating direction line sweep method combined with a multi-grid method. Compared with conventional single-grid methods, the multi-grid methods solve the equations on a hierarchy of grids so that all frequency components of the error are reduced at comparable rates. Inexpensive iteration on the coarse grid rapidly diminishes exactly those components of the error that are so difficult and expensive to reduce by fine grid iteration alone. This results in a dramatic reduction of solution time, especially for the dynamic simulation, since it involves repeated solutions of the discretized Reynolds equation. An adaptive mesh method is also implemented in the program, which can adjust the grid distribution according to the pressure gradient. This usually results in a better usage of the available grid points. The slider's equations of motion are solved by a Newmark-β integration method to achieve high accuracy and less frequency distortion as

compared to other commonly used methods. The numerical integration of the coupled equations begins with the estimated displacements of the slider based on the velocities of the previous time step. Then the new displacements are calculated by considering the air bearing pressure and suspension forces at that configuration. These new displacements are compared with the results of the previous iteration step. The iteration ends when the maximum relative change of displacements is smaller than a certain number, which, then gives the final displacements of the slider at that time step.

The dynamic analysis starts with the initialization of the fly height, pitch, roll and the corresponding velocities. The simulator then solves the slider's response to one or a combination of dynamic inputs. A number of dynamic effects on the slider's fly performance can be studied using the simulator. Among these are:

Disk Asperities: This type of analysis tracks the slider's response to the passage of asperities on the disk surface. Five types of asperities are available; the sinusoidal asperity, the ellipsoidal asperity, the cylindrical asperity, the rectangular asperity and the asperity with arbitrary cross-sectional profile. Their lateral size, height and orientation are adjustable.

Initial Impulse: Initial impulses are realized numerically by applying initial velocities to the slider. The slider's initial impulse responses can be used to obtain the air bearing stiffness and damping ratios using a modal analysis software developed at CML (Zeng, Chen and Bogy 1996).

Point by Point Disk Track Profile: To have the most realistic simulation of a slider flying over a rough disk surface, the simulator allows the direct input of point by point track profile data. At each time step, the film thickness distribution under the slider is obtained through interpolation of the track profile. With this new film thickness distribution, the coupled system of equations is solved. One application of this feature is a numerical estimation of the head-disk spacing modulation caused by the moving disk surface profile.

Integration of Suspension Dynamics: With the head-disk spacing in hard disk drives rapidly approaching sub-25nm levels, the suspension assembly dynamics may contribute

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significantly to the overall dynamics of the slider. To obtain an analysis of this contribution, modal analysis of the suspension is employed in the simulator to represent the suspension's effect on the slider's dynamics. The dynamic response of the suspension assembly is represented by a linear truncated combination of mode shapes.

Numerical Generation of Waviness on Disk Surface: Five types of disk waviness can be numerically generated by the program. They are the sinusoidal wave, the ellipsoidal asperity wave, the cylindrical asperity wave, the rectangular asperity wave and the asperity wave with arbitrary cross-sectional profile. The waviness can be either one-dimensional or two-dimensional. They have adjustable wavelength, amplitude and orientation. The radial zone where each waviness exists can also be defined by the input.

Time-Dependent Disk Velocity: The program allows the disk velocity to be variable with time. This is usually used for landing/take-off simulations. The time-dependent velocity data consists of pairs of (time, velocity) points. A linear relationship between adjacent data points is assumed. For landing/take-off studies, the simulation can be performed to/from zero disk speed. However, in these cases, an asperity-based contact model should be invoked to ensure a meaningful result.

Asperity Contact: Two asperity-based contact models are implemented in the program: the GW model (Greenwood and Williamson 1966) and the elastic-plastic model (Chang, Etsion and Bogy 1987). Both are probabilistic models. The rough surface is represented by a collection of asperities. The surface roughness is assumed to be random, isotropic and Gaussian. The contact stresses are assumed to depend upon the relative profile of the two surfaces in contact, i.e. upon the shape of the gap between them before loading. The system may then be replaced by a flat, rigid surface in contact with a body having a composite modulus and a profile, which results in the same undeformed gap between the surfaces. For the GW model, it is assumed that the contacting asperities deform elastically according to Hertz theory. The elastic-plastic model is similar to the GW model but requires volume conservation of a certain control volume of plastically deformed asperities. The friction force is assumed to follow Coulomb's law; the

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product of the normal contact force and a friction coefficient. During the simulation, the program computes at each time step the expected values of the normal contact force, the contact moments and the friction force based on the film thickness distribution. These forces and moments are then used to calculate the motion of the slider.

Track Seeking Motion: Track access is a process for the slider to move from one track to another. This process involves head motion as well as the dynamics of the suspension. The radial displacement of the slider changes its skew angle and the relative disk velocity, while the slider's accelerations introduce inertia forces. Both of these can adversely affect the spacing between the slider and disk. A time dependent head accessing acceleration profile is imposed and the head velocities are obtained by numerical integration. During the track access motion, the program calculates at each time step the updated radial location, skew angle and relative velocity of the disk surface at each grid point in the bearing. The inertia force acting on the suspension assembly may have significant influence on the spacing modulation for today's high performance disk drives. To effectively include this contribution, we perform the integration of the suspension assembly dynamics using modal analysis.

Zone Texture/Transition Zone Profile: So-called "zone texturing" is one of the approaches to reduce the stiction force during take-off and still allow the use of very smooth disk surfaces in the data region. In this approach, a small annular ring of texture with relatively large surface roughness is provided for the area where the slider starts and stops, while in the data zone, where the slider flies over the disk, the surface is made very smooth. There is a transition zone between the texture zone and the smooth data zone, which is produced during the manufacturing process. The radial zone surface profile is defined by three points in the radial direction. This feature can also be used to describe the radial disk edge profile.

Numerical Generation of Waviness/Asperities on the Slider: Similarly to the disk surface, waviness/asperities can also be numerically generated for the slider surface.

Disk Flutter: The disk flutter simulation provides information on how the slider responds to disk vibrations. Here a vertical sinusoidal flutter is used. The flutter frequency and amplitude can be adjusted.

2 Installation and Setup

2.1 Main Changes

- This version can handle the rail.dat format for both quick300 and quick416 (the new format).

- It can handle the case of one rail having different wall profiles.

- It can handle sliders with *negative* or very small center trailing edge nominal flying height (*hm* in *dynamics.def*).

- It can simulate the slider's response to waviness and asperities with arbitrary cross-sectional profiles defined by *a1.dat* or *w1.dat*, etc.

- It can output the disk topography under the slider at three specified instants. Please note that the *dynamics.def* for **dyn421 has one extra line (imediately before "**Numerical generation of Slider Surface Topagraphy**")** **to specify three time instants (in seconds)** to accommodate this feature with the presence of disk asperities (*nasper≥1*) or waviness (*nwave≥1*), see the included *dynamics.def* for details.

- A pre-compiled executable for windows95 or windows NT is included under the BIN directory. It's named *dyn421w.exe.* This version is fully optimized and compiled as a 32-bit windows console application. This version runs significantly faster than previous release.

2.2 File Structures

The file *dyn421.tgz* is a Unix compressed archive file. After you use the Unix command, *gunzip dyn421.tgz; tar xvf dyn421.tar,* you will get the following directories and files under the *CML_dyn421* directory:

- Directory *SRC_DEC* contains FORTRAN source code *dyn421.f* for DEC Alpha which is updated from *dyn417.f*.

- Directory *SRC_IBM* contains FORTRAN source code *dyn421r.f* for IBM RS/6000 which is updated from *dyn417r.f*.

- Directory *POST* contains sample Matlab scripts for postprocessing *rail2d.m, history.m, p3d.m*

  1. *rail2d.m* displays the 2-D rail shape. Usage: *rail2d.*

  2. *history.m* displays the settling history of a given point. To show the settling history at point 2 defined in *rail.dat*, type *history(2)*

  3. *p3d.m* displays the 3-dimensional pressure profile, type *p3d*

- Directory *BUMP* contains input files for the sample calculation of the bump response. Included files are *dynamics.def, rail.dat, x.dat, y.dat, a1.dat.*

- Directory *IMPULSE* contains input files for the sample calculation of the impulse responses. Included files are *dynamics.def, rail.dat, x.dat, y.dat*

- Directory *SPACING* contains input files for the sample calculation of the spacing modulation over a "supersmooth" disk. Included files are *dynamics.def, rail.dat, x.dat, y.dat, wave.def*

- Directory *SEEK*: input files for the sample calculation of the track seeking dynamics. Included files are *dynamics.def, rail.dat, x.dat, y.dat*. You need to copy the two files under the *FEM* directory to run the simulation

- Directory *CSS* contains input files for the sample calculation of the CSS. Included files are *dynamics.def, rail.dat, x.dat, y.dat* .

- Directory *FEM* contains FEM files of a suspension *fmesh.inp, fmodes.ext*

- Directory *BIN*: Executable file can be put here.

2.3 Compilation

If your workstation is an IBM/RS6000 or similar model, then go to the *SRC_IBM* directory. After you run the command, *f77 -O3 -o dyn421r dyn421r.f,* you can get the executable file *dyn421r.*

If your workstation is a DEC/Alpha or similar model, then go to the *SRC_DEC* directory. After you run the command *f77 -O4 -o dyn421 dyn421.f*, you will get the executable file: *dyn421.*

For other models, you can first try to follow the instructions for IBM workstation. Please note that the file *common.fi* must be put under the current directory to do the compilation.

2.4 Installation

The executable file *dyn421* should be included in the search path. We suggest that you unpack the file under the */usr/local* directory. Then you can copy the executable file *dyn421* to */usr/local/CML_dyn421/BIN* directory. The dynamic simulator can be run after you add */usr/local/CML_dyn421/BIN* to the search path by editing *.cshrc* for C shell or *.profile* for Bourne shell. A simpler way is to run the command,

$$ln -sf /usr/local/CML\_dyn421/BIN/dyn421 \ \ dyn421$$

under the */usr/local/bin* directory.

To run a simulation, e.g., the bump response case, change directory to *BUMP* and type *dyn421*

Any graphic package can be used to do the post-processing. Please see section 3.4 for the description of the data structure output files. If you have MATLAB, then the Matlab scripts included in directory *POST* can be used to view the simulation results. The path */usr/local/CML_Dyn421/POST* should be added to the MATLAB search path by editing the *.matlabrc* file. You can also simply copy all the MATLAB scripts from the *POST* directory to the current directory.

3 Input and Output Data Files

3.1 Data Input Summaries ('dynamics.def').

***********************Problem Definition************************

xl	yl	xg	yg	zg	halt
2.05e-3	0.7805	0.5	0.0	0.105	0.0
f0	xf0	yf0	amz	aip	air
3.0e-3	0.5	0.0	6.0e-6	2.18e-10	1.36e-10
rpm	dt	tf	ra	rif	rof
5400.0	1.0e-6	0.001	23.0e-3	10.0e-3	30.0e-3

************************Suspension*************************

iact	xact	dact	vact	ske	
1	38.0e-3	0.0	0.0	-9.1	
isusp	nmodes	ncg	alfa	beta	
0	10	2149	60.0	1.0e-5	
skz	skp	skr	scz	scp	scr
18.0	1.146e-2	1.432e-2	0.002	1.58e-6	1.4e-6

*********************Initial Flying Condition*********************

hm	hp	hr	vz	vp	vr
2.9e-7	165.0e-6	158.0e-9	0.0	0.0	0.0

***********************Solution Control************************

iqpo	akmax	emax	idisc
5	1.0e-7	1.0e-4	1

***********************Grid Control*************************

iadpt	isymmetry	ioldgrid	nx	ny	nsx	nsy
1	0	0	98	98	1	1

xnt(i), i=2,nsx
0.0
nxt(i), i=2,nsx
0
dxr(i), i=1,nsx
1.0
ynt(i), i=2, nsy
0.0
nyt(i), i=2,nsy
0
dyr(i), i=1,nsy
1.0

difmax	decay	ipmax
40.0	40.0	0

******************Point by Point Disk Track Profile*****************

ims	nfx	dinit
0	1009	3.2

************Numerical Generation of Disk Surface Topography**********

nwave	nzone	nasper

0	0	2					
iwtype	wamp	wang	wthx	wthy	wpdx	wpdy	wrs wre
zr1	zh1	zr2	zh2		zr3	zh3	
iatype	aamp	aang	alocx	alocy	asizx	asizy	
3	10.e-9	0.0	0.500e-3	0.0e-3	0.50e-4	2.0e-3	
4	1.0	0.0	1.000e-3	0.0e-3	0.50e-4	0.5e-4	

0.08e-03   0.11e-03   0.3e-03

************Numerical Generation of Slider Surface Topagraphy*********

nswave	nsasper					
0	0					
iswtype	swamp	swang	swthx	swthy	swpdx	swpdy
isatype	saamp	saang	salocx	salocy	sasizx	sasizy

**********************Track Seeking Motion********************

nap
0
tac   aac

****************Time-Dependent Disk Velocity Profile***************

nvp
0
tvp   vtd

*********************Sinusoidal Disk Flutter************************

iflut	tsft	teft	fqft	amft
0	0	0.003	100000.0	10.0e-9

***********************Asperity Contact************************

icmod	ey	ydst	pratio	frcoe
2	9.7135e+10	1.0e+10	0.3	0.3

ncz
1

sikm	ceta	rasper	rcts	rcte
3.0e-9	2.0e+12	10.0e-9	10.0e-3	30.0e-3

***********************End of Input Data***********************

3.2 Input File *dynamics.def*

 The file *dynamics.def* contains the parameters which define the slider geometry, the flying conditions and the dynamic inputs. Please note that in current version **this file has one more line** after the definition of asperities (imediately before the line "**Numerical Generation of Slider Surface Topagraphy**") to specify three time instants (in seconds) to output the disk topography **if nwave≥1 or nasper≥1**; please see the above sample *dynamics.def* for details.

3.2.1 *Problem definition*

      xl   : slider length [m].

yl   : slider width normalized with xl.

xg   : slider gravity x-position, normalized with xl, starting from leading edge.

yg   : slider gravity y-position, normalized with xl, starting from center

                  towards outer edge.

zg   : distance from the top of the slider to slider's gravity center in   z

                  direction, normalized with xl.

halt   : altitude above sea level [m].

f0   : suspension load [kg].

xf0   : load x-position, normalized with xl, starting from leading edge.

yf0   : load y-position, normalized with xl, starting from center towards outer

                  edge.
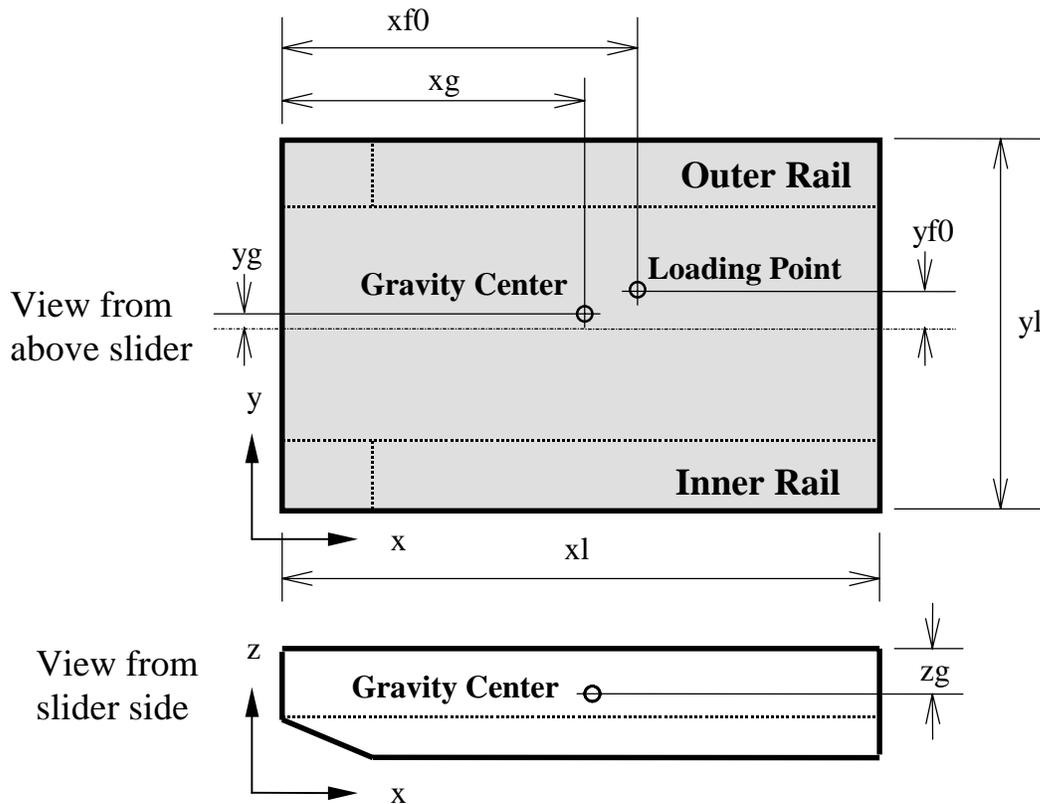
amz   : slider mass [kg].

aip, air   : slider pitch and roll moments of inertia, respectively [kg$\times$ m^2].

rpm   : disk revolutions per minute. It is initial rpm if the disk speed is time-

dependent (nvp > 0).

dt, tf   : time step and total time duration of the simulation, respectively [s].

ra   : radial position of the slider's gravity center [m]. It is initial radial

position for the case of the off-track motion.

rif, rof   : flyable inner and outer radial positions of the slider's gravity center,

respectively [m].

3.2.2 *Suspension*

iact   : 0 = no actuator; 1 = inline actuator.

xact   : length of actuator arm [m].

dact   : angular position of actuator with respect to the reference position [rad].
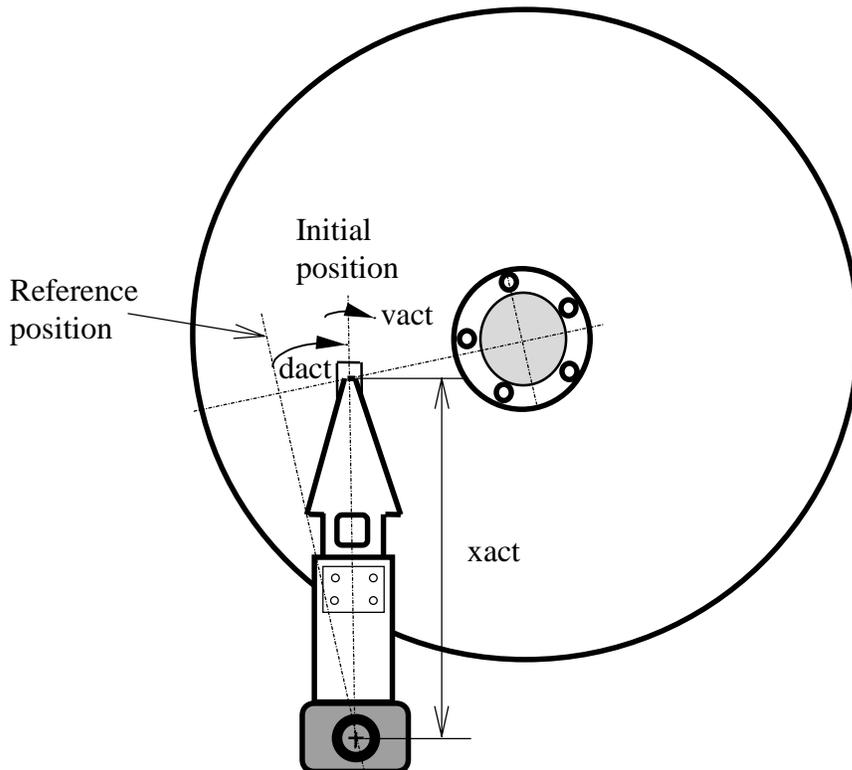
vact   : angular velocity of actuator, positive velocity indicates that slider moves

from OD to ID [rad/s].
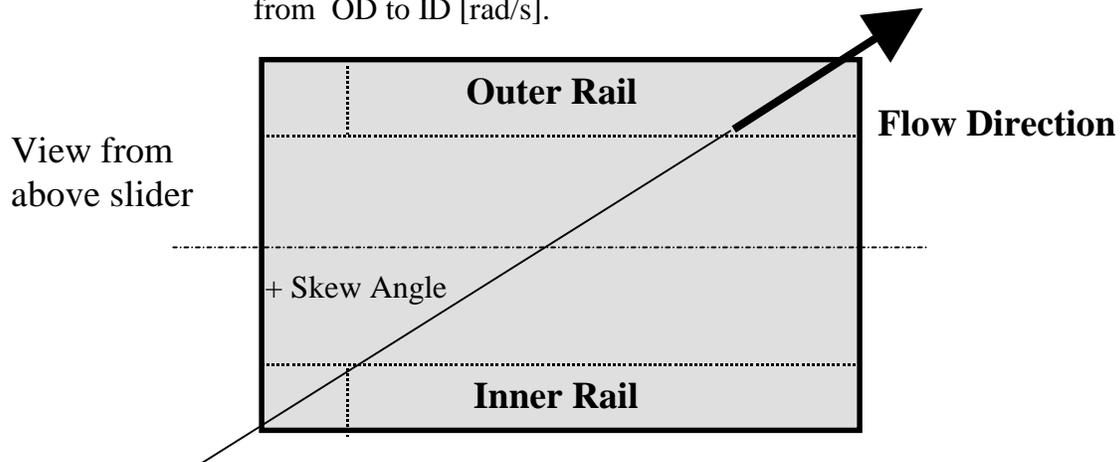
skew   : initial skew angle [deg], positive skew implies that the air flows from the

inner rail to the outer rail.

isusp   : 0 = using suspension stiffness and damping coefficients; 1 = integrating

the suspension dynamics by modal analysis. When isusp = 1, two files

fmodes.ext and *fmesh.inp* are needed. The file *fmodes.ext* contains

the natural frequencies and modal shapes. The file *fmesh.inp* is the

ABAQUS input file.

nmodes   : number of truncated suspension mode shapes. Used if isusp = 1.

ncg   : node number for the slider's gravity center defined in the ABAQUS input

file. Used if isusp = 1.

alfa   : mass proportional suspension damping [s^{-1}]. Used if isusp = 1.

beta   : stiffness proportional suspension damping [s]. Used if isusp = 1.

skz   : vertical suspension stiffness coefficient [N/m]. Used if isusp = 0.

skp, skr   : pitch and roll suspension stiffness coefficients, respectively [N×m/rad].

Used if isusp = 0.

scz   : vertical suspension damping coefficient [N×s/m]. Used if isusp = 0.

scp, scr   : pitch and roll suspension damping coefficients, respectively[N×m×s/rad].

Used if   isusp = 0.

3.2.3 *Initial flying condition*

hm   : initial nominal trailing edge center fly height [m]. Note that the reference point is on the nominal plane with pitch and roll, not including crown, camber or twist. Hm can be negative for current version.

hp, hr   : initial pitch and roll, respectively [rad], positive roll indicates that the outer rail flies higher that the inner rail.

vz   : initial vertical impulse velocity at the slider gravity center [m/s].

vp, vr   : initial pitch and roll impulse velocities, respectively [rad/s].

3.2.4 *Solution control*

iqpo   : slip flow models, 0 = continuum; 1 = first order slip model; 2 = second order slip model; 5 = Fukui-Kaneko linearized Boltzman equation model. 5 is the recommended choice.

akmax   : normalized residual of Reynolds equation, criterion of convergence of the solver.

emax   : normalized difference between the predicted and the final values of flying heights at each time step, the criterion of convergence for the solution of slider motion.

idisc   : different schemes for treating the convective term. 1 = power-law; 2 = central difference; 3 = upwind; 4 = hybrid. idisc = 1 is recommended.

3.2.5 *Grid control*

iadpt   : 0 = disable adaptive grid; 1 = use adaptive grid.

isymmetry   : 0 = manually generate the grid over the whole slider width; 1 = generate only half of the grid, which is symmetrical in the slider width direction. This has no effect when the adaptive grid option is used.

ioldgrid   : 0 = either use adaptive grid or manually generated grid; 1 = use the old grid locations in the files 'x.dat' and 'y.dat'.

nx, ny   : grid size in x and y directions, respectively, must be in the form of

      16n+2) because of multi grid method. In the case of using old grid

      locations, nx and ny can also be in the form of (16n+1) for consistency

      with the CML Air Bearing Design Program. Maximum nx and ny is 301.

nsx, nsy   : number of grid sections in x and y directions, respectively, for manually

      generated grids.

xnt(i)   : i from 2 to nsx, coordinates for the end of each section in the x direction,

      normalized with xl.

nxt(i)   : i from 2 to nsx, grid indices for the end of each section in the x direction.

dxr(i)   : i from 1 to nsx, ratio of grid size over previous one for each section in

      the x direction.

ynt(i)   : i from 2 to nsy, coordinates for the end of each section in the y direction,

      normalized with xl.

nyt(i)   : i from 2 to nsy, grid indices for the end of each section in the y direction.

dyr(i)   : i from 1 to nsy, ratio of grid size over previous one for each section in

      the y direction.

difmax   : used in the adaptive grid, a larger number allows a larger grid density

      difference.

decay   : used in the adaptive grid, a larger number has less smoothing effect, and

      the grid density depends more on the local pressure gradient and may

      change more abruptly.

ipmax   : used in the adaptive grid, 0 = use averaged pressure gradient in each

      direction along the cross section grid locations; 1 = use the maximum

   gradient in each direction along the cross section grid locations.

3.2.6 *Point by point disk track profile*

ims   : 0 = disable the point by point track profile; 1 = directly input the point by

      point track profile in the file *wave.def*.

nfx   : number of track profile points. Maximum nfx is 1200. Used if ims = 1.

dinit   : initial location of the slider's gravity center from the first track profile location, normalized with xl. Used if ims = 1.

3.2.7 *Numerical generation of disk surface topography*

nwave   : total number of waves. Correspondingly, there should be the same number of lines to define these waves following the 'iwtype' line. Maximum nwave is 40.

nzone   : number of the radial zone profiles. Correspondingly, there should be the same number of lines to define the zone profiles following the 'zr1' line. Each zone profile is defined by three radial points. The program can input up to 40 radial zone profiles.

nasper   : number of asperities. Correspondingly, there should be the same number of lines to define the asperities following the 'iatype' line. Up to 40 asperities can be distributed over the disk surface.

iwtype   : waviness type. 0 = sinusoidal wave; 1 = ellipsoidal asperity wave; 2 = cylindrical wave; 3 = rectangular asperity wave; 4 = wave with cross-sectional profile defined in files: *w1.dat*, *w2.dat*, etc.

wamp   : waviness amplitude [m]. **Note that for *iwtype=4* this parameter is used to indicate the input profile number, e.g., *1.0* corresponds to *w1.dat*.**

wang   : waviness orientation angle with respect to the disk rotation direction [deg].

wthx,wthy   : wavelengths or repetition distances for the asperities in X and Y directions, respectively [m]. If one of them is zero, it implies the infinite wavelength in that direction.
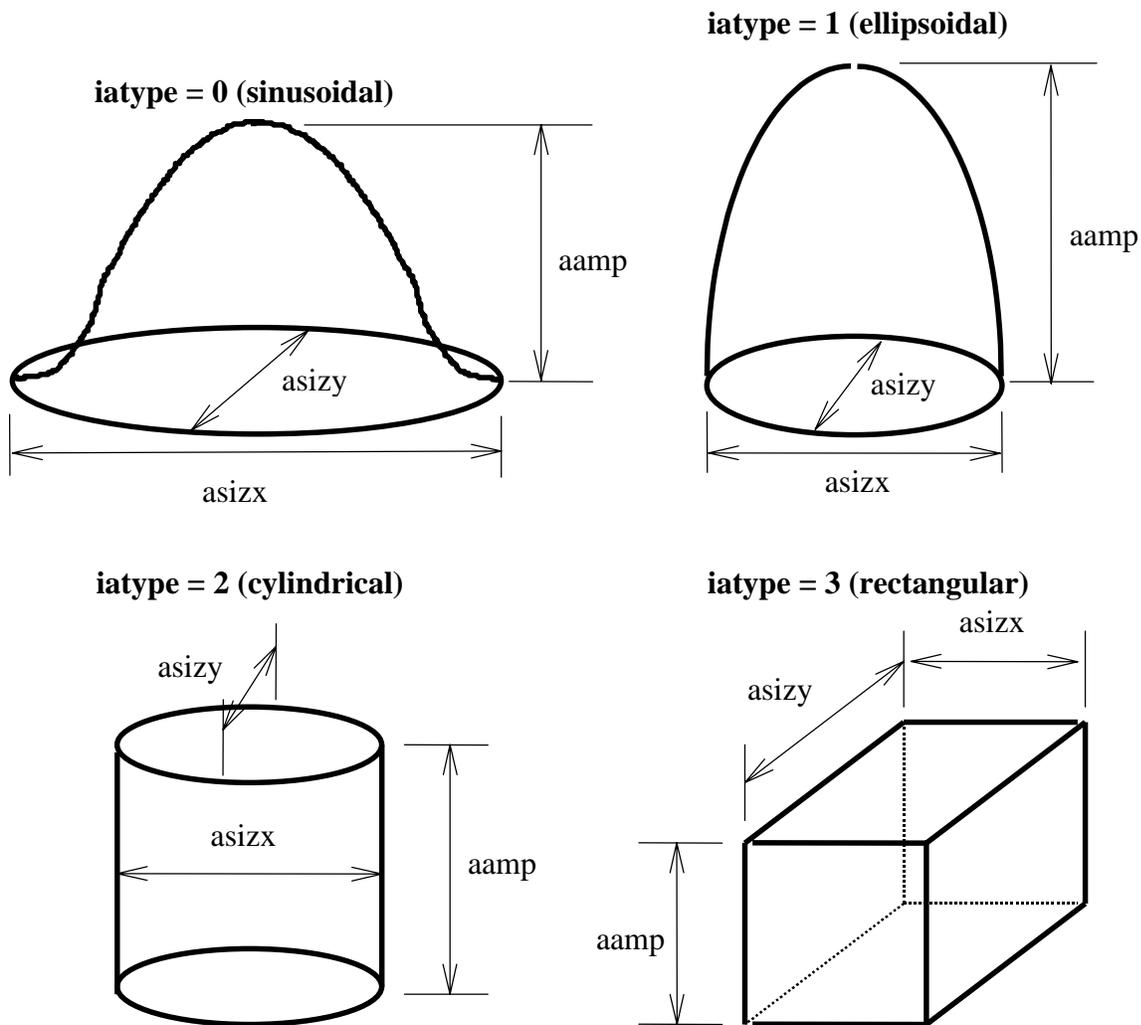
Disk Rotation Direction
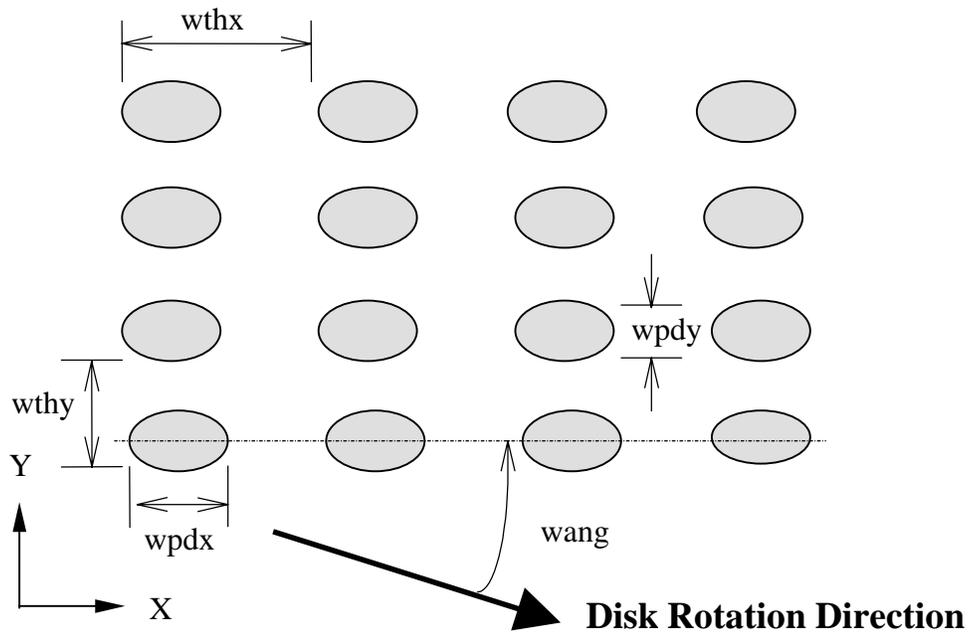
wpdx,wpdy   : pulse widths in X and Y directions, respectively [m]. If one of them is zero, it means the infinite pulse width in that direction. Not used for sinusoidal waviness.

wrs, wre   : starting and ending radii, respectively [m].

zr_n, zh_n : radius and height of point *n* (*n*=1, 2, 3), respectively [m]. Points 1 and 3 should be two boundary points. A parabolic functional relationship is assumed to exist for the three points.
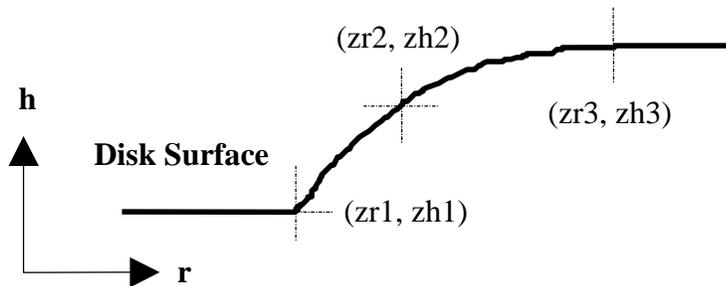
iatype   : asperity type. 0 = sinusoidal; 1 = ellipsoidal; 2 = cylindrical; 3 =

   rectangular; 4=arbitrary cross-section profile defined by *a1.dat*, etc.

iatype = 1 (ellipsoidal)

iatype = 0 (sinusoidal)

aamp

asizy

asizx

aamp

asizy

asizx

iatype = 2 (cylindrical)   **iatype = 3 (rectangular)**

asizy

asizx

asizx

asizy

aamp

aamp

aamp   : asperity height [m]. **Note that this parameter is used to indicate the**

         input profile number for *fatype=4,* e.g., *1.0* corresponds to *a1.dat*.

aang   : asperity orientation angle with respect to the disk rotation direction [deg].

alocx,alocy : asperity center location measured from the slider's gravity center at

         initial time in disk rotation and radial directions, respectively [m].

asizx,asizy   : asperity footprint lengths in disk rotation and radial directions, respectively [m]. If one of them is zero, it implies the infinite size in that direction.
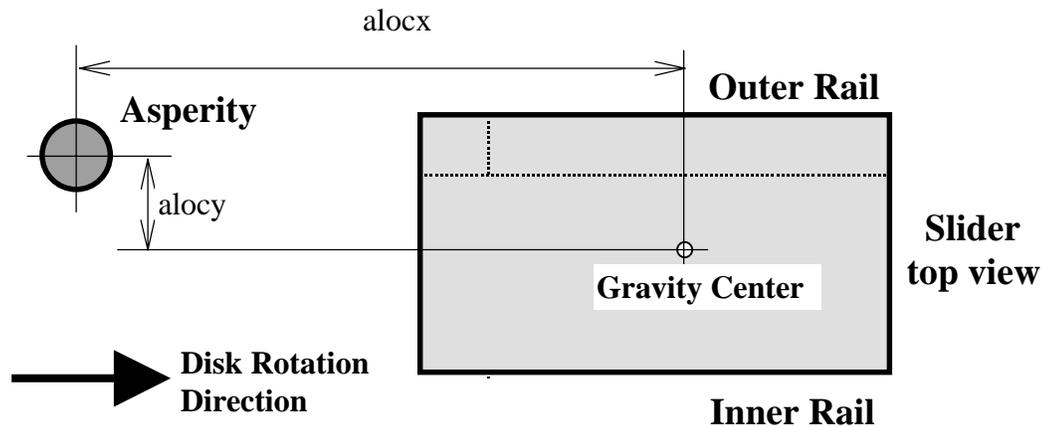
3.2.8 *Numerical generation of slider surface topography*

nswave   : total number of waves on slider surface. Correspondingly, there should be the same number of lines to define these waves following the 'iswtype' line. Maximum nswave is 40.

nsasper   : number of asperities on slider surface. Correspondingly, there should be the same number of lines to define the asperities following the 'isatype' line. The program can generate up to 40 asperities over the slider surface.

iswtype   : waviness type. 0 = sinusoidal wave; 1 = ellipsoidal asperity wave; 2 = cylindrical wave; 3 = rectangular asperity wave.

swamp   : waviness amplitude [m].

swang   : waviness orientation angle with respect to x direction [deg].

swthx,swthy   : wavelengths or repetition distances for the asperities in x and y directions, respectively [m]. If one of them is zero, it implies the infinite wavelength in that direction.

swpdx,swpdy   : pulse widths in x and y directions, respectively [m]. Not used for sinusoidal waviness. If one of them is zero, it means the infinite pulse width in that direction.

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isatype   : asperity type. 0 = sinusoidal; 1 = ellipsoidal; 2 = cylindrical; 3 =

rectangular.

saamp   : asperity height [m].

saang   : asperity orientation angle with respect to x direction [deg].
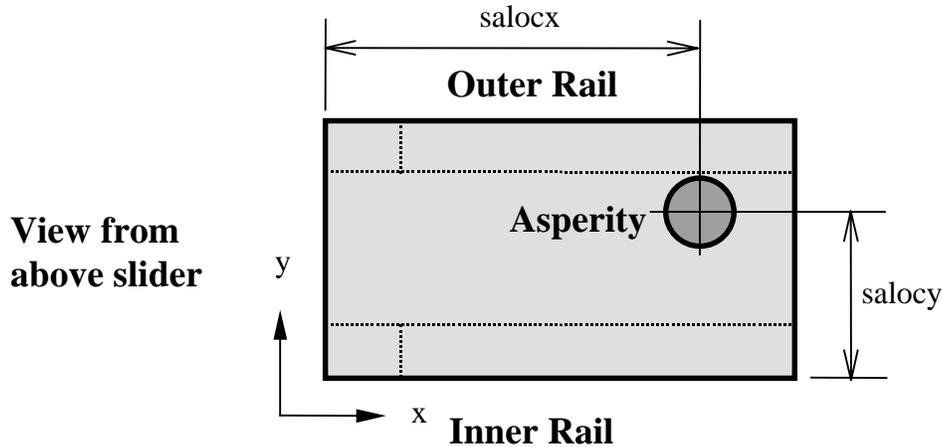
salocx, salocy : asperity center location in x direction from the slider's leading edge and

in y direction from the slider's inner rail boundary edge, respectively

[m].

sasizx,sasizy : asperity footprint lengths in x and y directions, respectively [m]. If one of

them is zero, it means the infinite size in that direction.

3.2.9 *Track seeking motion*

nap   : number of points to follow which describe the acceleration/deceleration

profile. A linear functional relationship is assumed to exist between

adjacent data points. The program can input up to 40 data points.

tac   : time [s].

aac   : angular acceleration [rad/s^2].

3.2.10 *Time-dependent disk velocity profile*

nvp   : number of points used in describing the time-dependent disk velocity

profile. Correspondingly, there should be the same number of data lines

to define the speed profile following the 'tvp' line. The program can take

up to 40 data points. If the simulation proceeds to times greater than that

of data input, the value of velocity at the largest time will be used.

tvp   : time [s].

vtd   : disk rotational speed [rpm].

3.2.11 *Disk flutter*

iflut   : 0 = disable disk flutter; 1 = disk flutter.

tsft, teft   : starting and ending times of disk flutter [s].

fqft   : flutter frequency [HZ].

amft   : flutter amplitude [m].

3.2.12 *Asperity Contact*

icmod   : 1 = GW model; 2 = elastic-plastic model.

ey   : composite elastic modulus [Pa].

ydst   : yield strength [Pa].

pratio   : Poisson's ratio.

frcoe   : friction coefficient.

ncz   : number of radial contact zones. There should be the same number of line

data to follow which describe the roughness of each zone. Maximum

ncz is 5.

sikm   : composite standard deviation of the asperity heights [m].

ceta   : area density of asperities [m^{-2}].

rasper   : asperity radius of curvature [m].

rcts, rcte   : starting and ending contact zone radii, respectively [m].

3.3 Input File *rail.dat*

The file *rail.dat* defines the rail shape and air bearing surface. The rail shapes are defined by piece-wise linear boundaries. A rail can be a step with a given recess depth, or it can be defined as a 'ramp', i.e., a flat plane having a specified orientation. Each rail may have a different recess depth. Normally, a zero recess is assigned to the main air bearing surface. The dynamic

simulator shares the same *rail.dat* file as the Air Bearing Design Program. The file format is the same as that of the *rail.dat* from the CML Air Bearing Design Program User's Manual (Sha and Bogy 1995) for **quick300** format, and CML Air Bearing Design Program (Version 4.0.17) and 32-bit Windows Interface (Grisso, Lu and Bogy 1997) for **quick400** and later format. Please note that this version of dynamic simulator can automatically recognize and read the *rail.dat* of both formats.

3.3.1 *Quick300 Format*

The first line in *rail.dat* indicates how many rails are defined and how many different recess heights they possess.

The data for each rail follow. First, the number of boundary points, the recess height index of the current rail and the number of points in the wall profile are given. The last number should be less than two if the rail is of the ramp type (the recess height index is 0). Next, the coordinates of the boundary points normalized with slider length are shown, with the origin at the inner leading edge. If the recess height index is 0, there is an additional line consisting of recess depths for the first three boundary points of the rail. Finally, if the wall profile has at least two points (otherwise a vertical wall is assumed), two more lines are used to describe it. The first line gives the coordinates of the points in terms of the normal distance to the nominal wall normalized by the slider length. Points with negative coordinates are inside the nominal rail boundary, and those with positive coordinates are outside the boundary. The second line contains the recess values (in meters) for the wall profile points.

After all the rails are defined, there is a line which gives the base recess depth (area not defined as rails), and rail recess depths in index order. All recess values are in meters. The next line shows taper length (normalized with slider length) and taper depth in meters. If a virtual taper exists, but is defined using 'ramps' instead of by the taper specification, the taper length should be set to the actual value, with zero taper depth at the front. The code will then try to resolve the taper end automatically when the adaptive grid is used.

The next line contains information on crown, twist and camber in meters. the crown is a longitudinal parabolic surface superimposed on the whole slider. A positive crown decreases the surface between the slider and the disk. The camber is the same as the crown except that it is in the transverse direction. The twist is given in terms of the relative height of four corners to the center. A positive twist increases the separation between the slider and the disk at the inner leading edge and the outer trailing edge, and decreases the separation at the outer leading and inner trailing edge.

The last two lines give the x and y normalized coordinates of four points on the slider, respectively. The program outputs the fly height at these four points.

3.3.2 *Quick400 Format*

The first two lines are the header. The third line contains the slider dimensions in meters: length, width and 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. Astep 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 as they were in version 3, 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 lines 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 meters. A negative value indicates that the point is inside the nominal rail boundary, while a positive value is outside. 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 taper have been chaged 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.

3.4 Other Input Files

The file *wave.def* is needed for the simulation using the point by point disk track profile (ims = 1). The file contains two columns of data: position (meters) in column 1 and height (meters) in column 2. To integrate the suspension dynamics by modal analysis, you need to have two files *fmodes.ext* and *fmesh.inp*. The file *fmodes.ext* stores the natural frequencies and modal shapes. The file *fmesh.inp* is the input file of the commercial finite element code ABAQUS. For fatype=4, the input files to define the cross-sectional profiles for the asperities, *a1.dat, a2.dat*, etc. are needed. For fwtype=4, the input files to define the cross-sectional profiles for the waviness, *w1.dat, w2.dat*, etc. are needed. The format for *a1.dat* or *w1.dat* is as follows: the first line specify the number of points used to specify the profile (less than 50 in current version), then the coordinates (radius and height) of those points (in meters) ensue.

3.5 Output Files.

The output file *fhhist.dat* contains slider settling history. There are five columns of data: time (s) in column 1, nominal fly height (m) in column 2, pitch (rad) in column 3, roll (rad) in column 4 and off-track displacement (m) in column 5. The file *hpoint.dat* stores the displacements (measured from the mean disk surface) at the four points defined in *rail.dat*. The corresponding disk floor heights at these four points are contained in the file *hfloor.dat*. The file *track.dat* stores the following data: time (s) in column 1, radial position (m) in column 2, accessing velocity (m/s) in column 3, accessing acceleration (m/s^2) in column 4, geometrical skew angle (deg) in column 5, effective skew angle (deg) in column 6 and disk speed (rpm) in

column 7. The effective skew angle is the angle between the slider's length axis and the relative disk velocity vector.

Air bearing force history is stored in the file *load.dat* which has four columns of data: time (s) in column 1, air bearing force (kg) in column 2, normalized air bearing force center XF in column 3, normalized air bearing force center YF in column 4, positive air bearing force (kg) in column 5, and negative air bearing force (kg) in column 6. The contact force history is saved in the file *contact.dat*. The file contains five columns of data: time(s) in column 1, the normal contact force (kg) in column 2, the contact moments in pitch direction (column 3) and roll direction (column 4) (N×m) as well as the ratio of the real to apparent contact area in column 5.

The files *x.dat* and *y.dat* contain the normalized x and y coordinates, respectively. The pressure matrix is stored in the file *p2.dat*. The files *disktop1.dat, disktop2.dat etc*. store the disk topography at the specified time.

4 Examples of Dynamic Simulations

This section presents four sample simulations to demonstrate some of the features provided by the simulator. A 30% U slider was used for the sample calculations. Figure 1 shows its air bearing surface. The slider has a recess depth of 3.556 μm and a crown of 20.32 nm. Figure 2 shows its air bearing pressure profile. The disk rotational speed is 7200 rpm, the disk radius at which the slider flies is 20.5 mm, the skew angle is 7.524 degrees, and the suspension preload is 2.5 g.

4.1 Impulse responses

Figure 3 shows the slider's dynamic responses in both the time and frequency domain to a vertical impulse of 0.2 cm/sec. The impulse responses can be used to obtain the air bearing's stiffness and damping ratios using a modal analysis software developed at CML (Zeng, Chen and Bogy 1996).

4.2 Bump Responses

Figure 4 illustrates the slider's response to the passage of a 10nm high rectangular bump on the disk surface. The bump has a width of 25μm and length of 2mm. The bump is initially located 1.5mm ahead of the slider's gravity center. The slider reacts slightly as the bump travels under the front taper and then experiences larger oscillation as the bump encounters the more sensitive lower film thickness portions of the bearing. Please note that the sample *dynamics.def* includes one additional bump of type 4.

4.3 Track seeking dynamics

In this simulation, the suspension dynamics is integrated by modal analysis (isusp = 1). The eigenvalue solution is first sought using ABAQUS, then the first 10 modes are used in the air bearing simulation to represent the suspension dynamics during the track seeking event. Figure 5 shows changes of the geometrical skew angle, flying height at a point located at the trailing edge of the outer rail, pitch and roll. In Figure 5 we plot the results of two separate simulations together. The solid and dashed lines show the results for the ID to OD and OD to ID seeking processes respectively. The flying height modulation is closely related to the roll motion caused by the inertia force. The pitch and the flying height change do not appear to be related. The pitch is affected very little by the slider's inertia force of the off-track motion. Figure 5 also shows that a transient oscillation in roll follows the sudden roll change due to the sudden action of the slider's inertia force.

4.4 Contact takeoff simulation

The dynamic simulator can be used to simulate the contact takeoff and landing process. This can be done by using the feature of " time-dependent disk velocity" as described in Section 1. A contact model needs to be chosen and the input parameter *ncz* has to be a value other than zero. Figure 6 shows the results of a contact takeoff simulation on the 30% U slider. In the figure, the contact force, center trailing edge nominal flying heght, pitch and roll are plotted against the disk velocity (in RPM). The elastic-plastic asperity-based contact model is used. We assume the distribution of asperity heights asperities is Gaussian with a standard deviation of 6 nm.

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Zeng, Q.-H., Chen, L. S. and Bogy, D. B, "A Modal Analysis Method for the Slider Air Bearings in Hard Disk Drives," *Technical Report No. 96-021*, Computer Mechanics Laboratory, U.C. Berkeley.
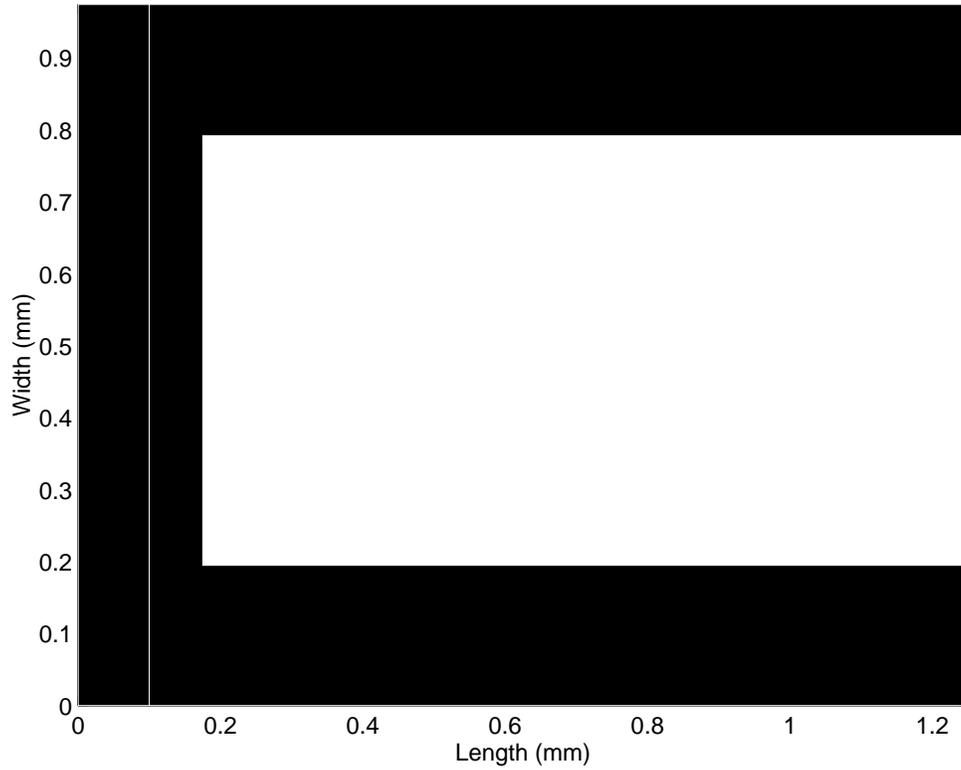
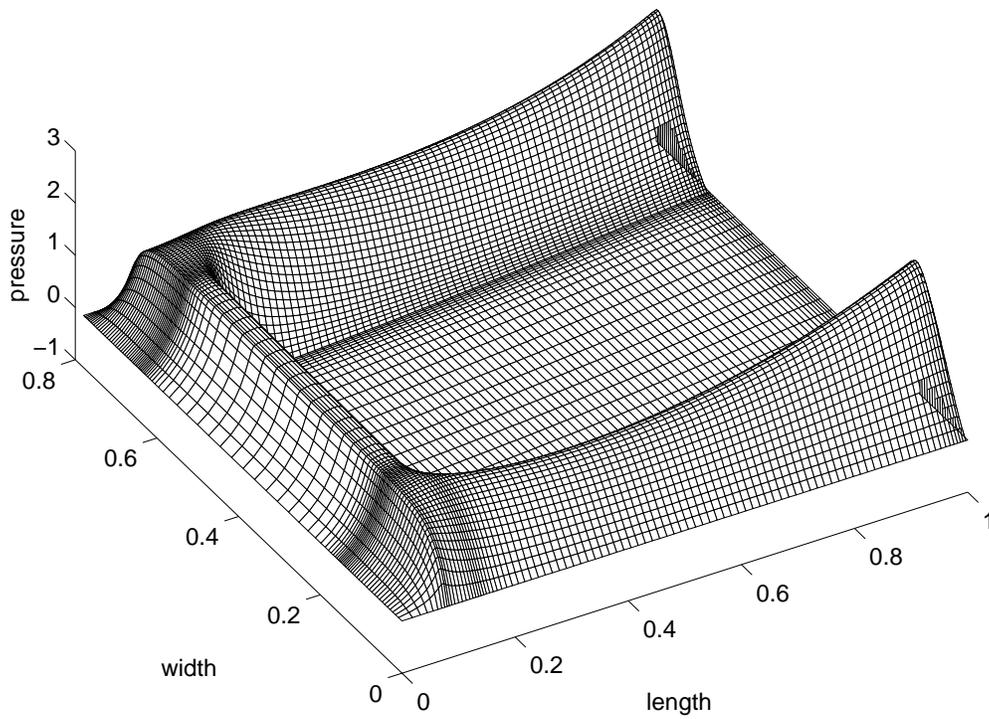**Figure 1 Air bearing surface of the 30% U slider**
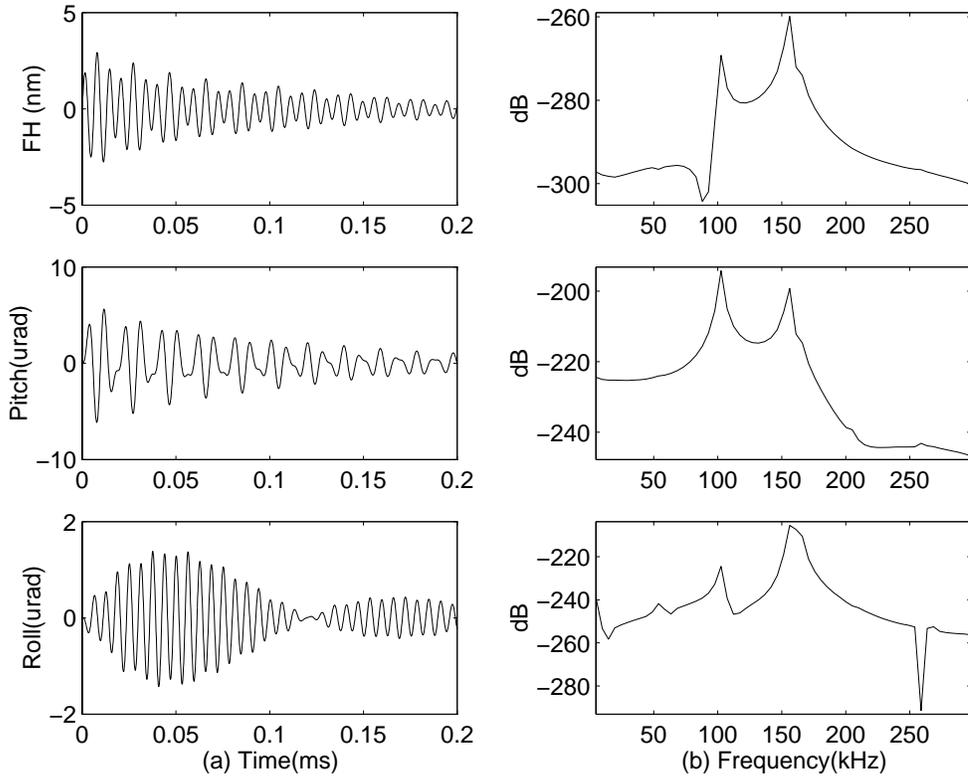

Figure 2 3-D pressure profile of the 30% U slider

Figure 3 Responses of the 30% U slider to a vertical impulse of 0.2cm/s
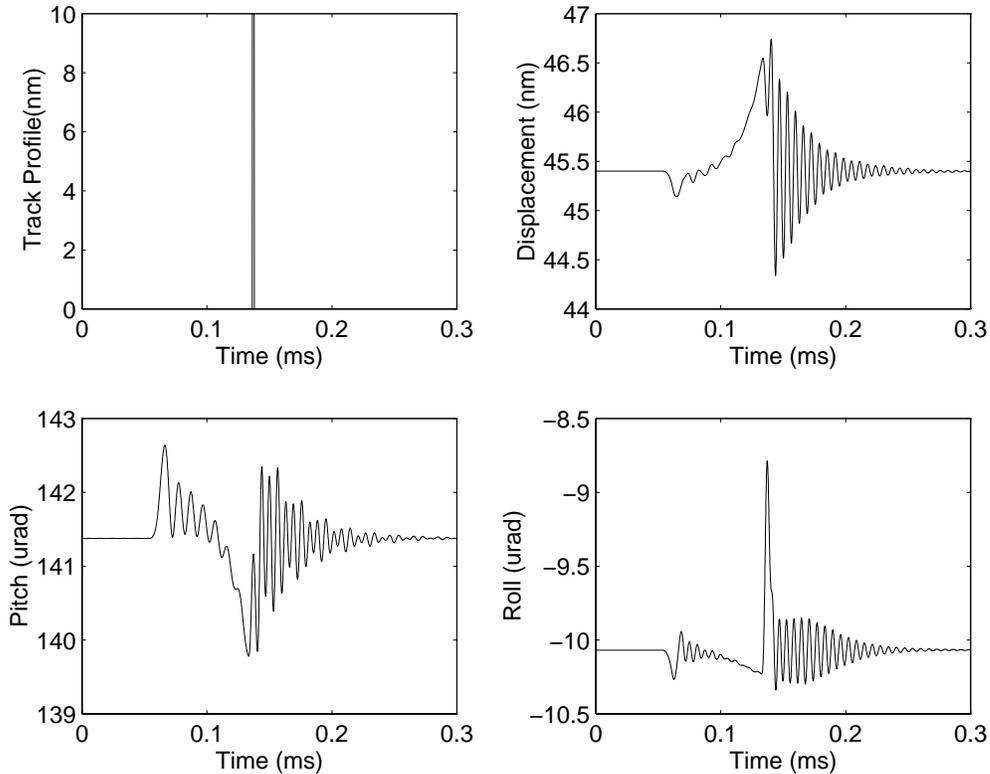

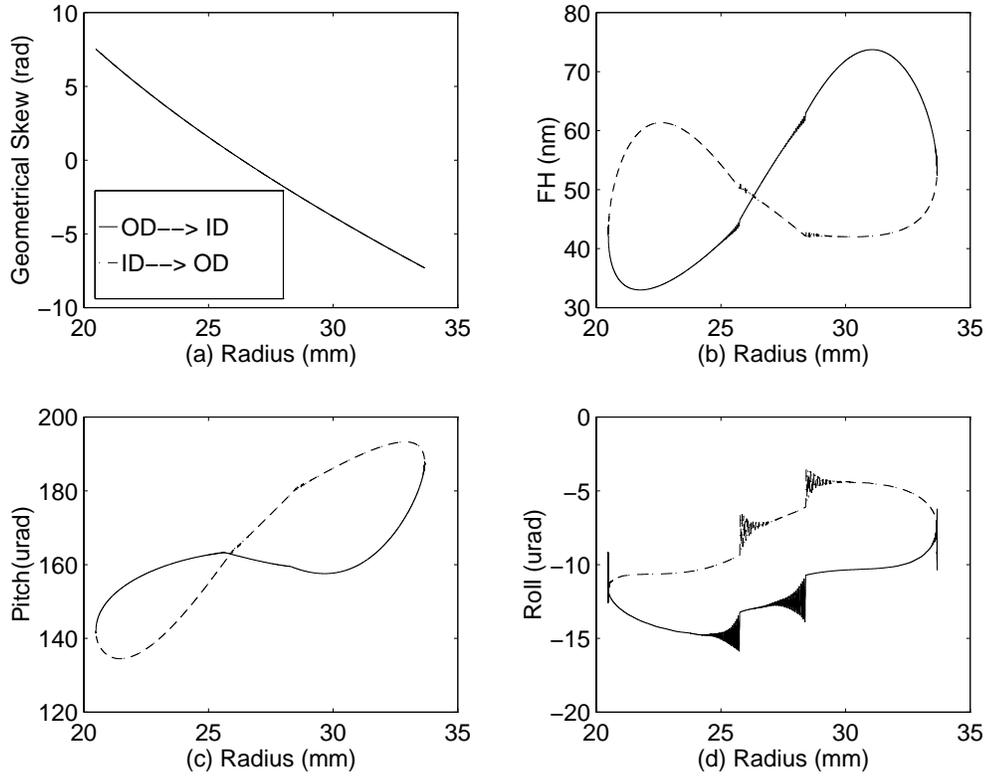**Figure 4 Responses of the 30% U slider to a 10 nm bump**

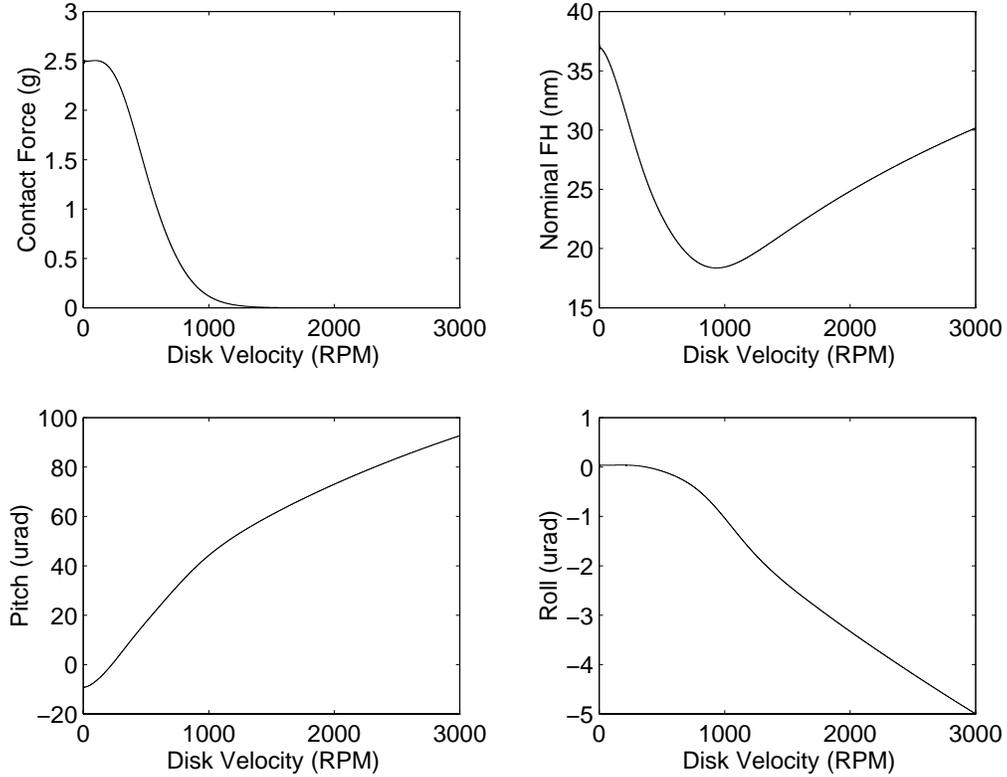**Figure 5 Flying characteristics of the 30% U slider during track-seeking**

Figure 6 Contact force, nominal flying height, pitch and roll history during contact takeoff