The CML Dynamic Load/Unload Simulator
(Version 421.40)

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Abstract

This report presents a detailed description of the dynamic load/unload (L/UL) simulator (Version 421.40) developed at the Computer Mechanics Laboratory at the University of California at Berkeley. This version incorporates many new features, such as a simplified 4 degree-of-freedom (DOF) model of suspension assemblies (including suspensions with limiters), improved models for slider/disk contact, a model to calculate the ramp force, static pitch and roll attitudes, output of minimum clearance, and adaptive time step. Determination of the suspension parameters for the L/UL simulation is discussed. Three examples are presented, one for loading and two for unloading (with different suspensions). More than ten post-processing programs written in MATLAB are also provided. It is believed that this simulator will be very useful for evaluating the L/UL performance of various air bearing designs and suspension-flexure systems.

1 Introduction

This report is a detailed manual for the new version (Version 421.40) of the dynamic load/unload (L/UL) simulator developed at the Computer Mechanics Laboratory at the University of California at Berkeley. The dynamic L/UL process is determined primarily by the air bearing slider dynamics together with the suspension dynamics. In this version, the air bearing modeling is the same as the CML air bearing dynamic simulator [1], and the suspension is modeled as a simplified 4-DOFs system, which was fully described in our previous report [2]. Before users attempt to implement this new simulator they should become very familiar with the two reports [1,2]. Other reports [3-6] are also very helpful for using the program. Knowledge of and experience with suspension dynamics are extremely important for determining the suspension parameters that are used in the L/UL simulation.

Compared with the old version (Version 421.10, [6]), we implemented many new features in this version. The main features are as follows.

1) Most of the features of the air bearing dynamic simulator are retained. Various features can be combined to simulate a more complicated process. For example, the effects of disk run-out on L/UL can be simulated by using disk flutter.
2) Both the load and unload processes can been simulated.
3) Positive and negative pressure sliders can be simulated.
4) The suspension assemblies are modeled by a 4-DOF systems with multiple states. Various suspension assemblies, such as those with or without a load dimple, and/or

with or without limiters, can be simulated. During the L/UL process the suspension parameters are changed based on the suspension state.

5) The contact condition changes at the dimple and limiters are modeled by discontinuous changes of the parameters.
6) Contact between a slider and disk is modeled by asperity contacts. The contact force and moments are calculated if the flying height is less than the specified glide height.
7) Impact between the slider and the disk during the L/UL process is modeled by elastic-plastic contact model. The impact force and moments are calculated if the flying height is less than zero. The parameters of the disk materials can be specified to be different from those used in asperity contact. If a large Young's modulus is specified, the results are similar to those from the impulse moment method. If the FH is less than 0.1 nm, the air bearing pressure is also approximately calculated. It is obvious that these contact models are limited. Therefore, the results may have only qualitative meaning if contacts occur. However, it is difficult to find a more accurate model for the contacts that is suitable to numerical simulation.
8) The static pitch and roll attitudes can be imposed in the simulation. The disturbances can be simulated by specifying the initial pitch and/or roll, and velocity of the slider.
9) The minimum clearance between the slider and the disk and the location with the minimum clearance during the L/UL process are reported in the data output.
10) The force applied by the ramp can also be obtained. It is very useful for determining the L/UL actuator torque and ramp wear.
11) The initial acceleration of the L/UL tab movement can be specified.

12) The time step is adaptively changed based on the slider size, L/UL speed, and suspension stiffness.

2 Installation and file structures

2.1 Unix version

The file *CML_d421d40.tar.gz* is a Unix compressed archive file. After using the Unix command:

```
gunzip CML_d421d40.tar.gz
tar –xvf CML_d421d40.tar
```

you will find the following directories and files under the *CML_dlul* directory.

1) Directory *source* contains the FORTRAN source code *d421d40.f* and two included files (**.bi*) for the DEC Alpha machine. The *d421* means this simulator is modified from the CML air bearing dynamic simulator version 4.21, and the *d40* means this is the dynamic L/UL simulator version 4.0.

2) Directory *mfiles* contains MATLAB m-files for post-processing. The functions of these files will be described in a later section.

3) Directory *example1* contains input files and results of the load process for a negative pressure slider incorporating a suspension with limiters and the L/UL tab that has an offset in the Y direction, as shown in Fig. 1.

4) Directory *example2* contains input files and results of an unload process for the slider incorporating a suspension with limiters and a L/UL tab that has no offset in the Y direction.

5) Directory *example3* contains input files and results of an unload process for the slider incorporating a suspension that is used in *example1*.

The FORTRAN source code should be compiled by a suitable FORTRAN compiler in the directory *source* to obtain an executable file *d421d40*. The executable file *d421d40* is copied to the directory *CML_dlul*. To run a simulation, e.g., the *example1,* you should change the current directory to *example1* and type *../d421d40* . To display the results, you can run MATLAB in the current directory, and type the following command in the MATLAB environment

```
>> path(path, '../mfiles')
```

Then, you can use the m-files to display the results in MATLAB. For example, by typing

```
>> forc5c(0,0)
```

you will obtain the five force histories in one figure of the L/UL process in gram units.

2.2 PC Windows version

The file *D421d40.zip* is a compressed file. Create the directory *CML_dlul* in the root directory of a hard disk drive, e.g., *C:\CML_dlul,* and copy *D421d40.zip* to this directory. You can use the pkunzip command or WinZip to extract the files saved in *D421d40.zip* into the *C:\CML_dlul* directory, and thereby get the *d421d40.exe* file and four sub-directories (*mfiles, example1, example2, example3*).

To run a simulation, e.g., *example1,* you should open a DOS window in the Windows environment, change the current directory to *example1* in the DOS window (*cd* *c:\CML_dlul\example1*), and type *..\d421d40*. To display the results, you need to run MATLAB, change the current directory to *c:\CML_dlul\example1*in the MATLAB environment

```
>> cd c:\CML_dlul\example1
```

and type the following command in the MATLAB environment

```
>> path(path, ‘c:\CML_dlul\mfiles’)
```

Then, you can use the m-files to display the results in MATLAB. For example, by typing

```
>> force1g(0,0)
```

you will obtain the force history in gram units as shown in Figure 3.

3 Procedure

The procedure for L/UL simulations is as follows:

1) Design the air bearing surfaces or input the air bearing design by using the CML air bearing design program [7]. Create the *rail.dat* file in Quick300 or Quick400 format.
2) Edit the L/UL simulator input file *dynamics.def*. The simple way is to copy this file from the examples and modify the related parameters.
3) Find the flying attitudes in the steady state, and create the grid.

   The following procedure is suggested. Use the design code to obtain the initial flying attitudes in the steady state. Then, run “no L/UL” (**L/UL = 0** in the *dynamics.def* file as described in the next section) simulation (**dt=1e-6, tf=.5~10e-3, iadpt=1, ioldgrid=0**). The flying attitudes in the steady state can be found from the last line of the output file *fhhist.dat,* and the grid is also obtained and has been saved in files *x.dat* and *y.dat*. Finally, remember to change **iadpt=0, ioldgrid=1,** and specify **dt**, **tf** and **L/UL** to the required values for the L/UL simulation. If the static pitch and roll are specified, you need to use this procedure to calculate the steady flying attitudes.

4) Perform the L/UL simulation. It may take several hours or days to complete. If impact occurs in the unload simulation, it takes much longer to complete because the time step is changed to 2% or 1% of the original time step in contact calculations.
5) Display the results by using the MATLAB m-files that are included in this simulator.

4 Input and output data files

4.1 Input file *rail.dat*

The file *rail.dat* defines the rail shape and air bearing surface. This file is generated by the CML design code [7]. The four “points of interest” are specified in this file. The flying height at these four points are calculated in the L/UL simulation. It is suggested that the four points be specified as the four corners of the slider, so it is easy to identify which corner hits the disk if it happens during the L/UL.

4.2 Input file dynamics.def

```
**********************Problem Definition*******************
 xl(m)      yl(/xl)    xg(/xl)    yg(/xl)    zg(/xl)    halt
 0.125e-2   0.800      0.5        0.0        0.12      0.0
 f0(kg)     xf0(xl)    yf0(/yl)   amz        aip        air
 0.25e-2    0.5        0.0        1.62e-6    6.15e-13   4.61e-13
 rpm        dt(s)      tf(s)      ra         ra_if      ra_of
 5400.0     2d-6       15e-3      31e-3      12.0e-3    47.0e-3
 ************************Suspension*************************
 iact       xact(m)    dact       vact       ske
 1          38.00e-3   0.0        0.0       -15.0
 isusp      nmodes     ncg        alfa       beta
 0          10         1000       60.0       1.0e-5
 skz        skp        skr        scz        scp        scr
 13.82      6.886e-5   7.049e-5   4.73e-5    2.82e-10   3.42e-10
 ******************Initial Flying Condition*****************
 hm(m)        hp(rad)      hr(rad)        vz(m/s) vp(rad/s)  vr(rad/s)
 0.275112E-07 0.152416E-03 0.166885E-04   0       0          0
 *******************Solution Control************************
```

```
 iqpo       akmax      emax       idisc
 5          1.0e-7     1.0e-4     1
 ********************Grid Control***************************
 iadapt     isymmetry  ioldgrid   nx   ny   nsx   nsy
 0          0          1          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
  1.000000
 difmax     decay      ipmax
 10.0       10.0       0
 ***********Point by Point Disk Track Profile***************
 ims        nfx        dinit
 0          4096       3.2
 ******Numerical Generation of Disk Surface Topography******
 nwave  nzone  nasper
 0      0       0
 iwtype wamp(m) wang(dg) wthx(m) wthy(m) wpdx(m) wpdy(m) wrs(m) wre(m)
 zr1(m)    zh1(m)   zr2(m)   zh2(m)   zr3(m)  zh3(m)
 iatype aamp(m) aang(dg) alocx(m) alocy(m)  asizx(m)  asizy(m)
 ****Numerical Generation of Slider Surface Topography******
 nswave  nsasper
 0       0
 istype  swamp(m)  swng(dg)  swthx(m)   swthy(m)   swpdx(m)  swpdy(m)
 isatype saamp(m)  saang(dg) salocx(m)  salocy(m)  sasizx(m) sasizy(m)
 ******************Track Accessing Motion*******************
 nap
 0
 tac(s)   aac(rad/s^2)
 *************Time-Dependent Disk Velocity*******************
 nvp
 0
 tvp(s)   vtd(RPM)
 ****************Sinusoidal Disk Flutter*******************
 iflut   tsft    teft    fqft      amft
 0       0       0.003   10000.0   10.0e-9
 ********************Asperity Contact**********************
 icmod   ey          ydst     pratio  frcoe
 1       100e+9      10e+9    0.3     0.3
 ncz
 1
 sikm(m) ceta(/m/m)  rasper(m) rcts(m)  rcte(m)  gldht
 2.0e-9  2.0e+11     1e-6      10.0e-3  50.0e-3  10.0e-9
***********************Dynamic Load/Unload ****************
L/UL, n/a       kz1      n/a     AccL/UL(m/ss)  v(L/ULspeed,m/s)
2     0         500      0       10000          100e-3
N_Sta, N_Par, n/a, n/a, n/a OutPr5, p@t1(ms), p@t2,   p@t3,  p@t4
4      4      0    0    0   1      .01        0.3     0.79   0.82
n/a,   n/a     n/a      S.pitch, S.roll, I_ey   I_ydst I_rad n/a n/a
```

```
0      0       0        10.0d-3  5.0d-3  100e+9 10e+9  10e-6 0   0
State_2 f21(gram) f22    n/a n/a   Stiffness matrix
        100      -2e-3   0   0
  4.7059e+02  -6.4629e+02  -5.1956e-03   5.3608e-03
 -6.4629e+02   9.0224e+02   1.4907e-02  -7.3546e-03
 -5.1956e-03   1.4907e-02   7.3044e-05  -4.3056e-08
  5.3608e-03  -7.3546e-03  -4.3056e-08   7.0547e-05
State_3 f31(gram) f32     n/a n/a   Stiffness matrix
       -2e-3     -.112    0   0
  2.3761e+01  -2.5262e+01  -1.9919e-02   2.4349e-04
 -2.5262e+01   3.9096e+01   3.5343e-02  -2.4290e-04
 -1.9919e-02   3.5343e-02   7.2297e-05  -2.1075e-07
  2.4349e-04  -2.4290e-04  -2.1075e-07   7.0489e-05
State_4 f41(gram) f42     n/a n/a  Stiffness matrix
      -.112      -100     0   0
  3.9758e+02  -5.5334e+02  -1.1029e-01   8.2594e-02
 -5.5334e+02   7.8509e+02   1.6302e-01  -1.1503e-01
 -1.1029e-01   1.6302e-01   9.4349e-05  -2.2901e-05
  8.2594e-02  -1.1503e-01  -2.2901e-05   5.8148e-04
```

The file *dynamics.def* contains a large number of parameters. Most of them are the same as described in report [1]. The parameters, which are important, different, or additional, and need more explanations, are discussed in detail next.

f0	suspension normal load (kg).
xf0(xl), yf0(/yl)	normalized coordinates of the load point. They must be same as **xg** and **yg.**
aip, air	effective inertia moments of the slider in the pitch and roll direction [$\text{kg}\times\text{m}^2$]. They are usually much larger than the values that are directly calculated from the slider's dimensions and density for pico-sliders [2].
rpm	disk revolutions per minute. You can try different RMP to obtain the best L/UL performance.
dt	time step (s). It will obviously affect the results if contacts occur. An adaptive factor t_a will be automatically generated based on parameters such as slider size, normal load, L/UL speed and suspension stiffness. Therefore, the time step used

	in the calculation is t_a*dt. If the user finds this time step is not good, he/she can change **dt**. A value of 1e-6 **dt** is suitable for most cases, but you can save calculation time and storage capacity by using a **dt** between 2e-6 and 5e-6.
tf	total time duration (s) of the simulation. It is better to specify a larger value to let the simulator automatically stop after the convergence criteria are reached.
ra	radial position of the slider's gravity center (m). We don't simulate the effects of the motion in the track seeking direction, so the position is the point at which the unload process is started, or the air flow starts to affect the slider during the load process.
ske	the skew angle (degree) at the specified radial position. A positive skew implies that the air flows from the inner rail to the outer rail.
isusp	fixed to 0. That corresponds to using suspension stiffness and damping coefficients.
skz, skp, skr, scz, scp, scr	stiffness and damping coefficients of the suspension in the free state. The stiffness should be calculated while the 4x4 stiffness matrices are calculated.
hm, hp, hr, vz, vp and **vr**	the initial nominal flying height (m), pitch, roll (rad) and velocities. For unloading, **hm, hp** and **hr** are the steady flying attitudes, and the **vz, vp** and **vr** are zero. For loading, the height is specified to the position at which the air flow starts to affect the slider's motion. The suspension vibration effects can be simulated by specified different **hp, hr** and velocities. **hp** and **hr** are relative to the static balance position, and they are different from the static pitch and roll.

iadpt	**1** = use adaptive grid to generate the grid; **0** = disable grid generation. Please read the previous section (procedure 3).
ioldgrid	1 = use the old grid saved in the *x.dat* and *y.dat* files; 0 = use adaptive grid. Please read the previous section (procedure 3).
nx, ny	grid size in the x and y directions, respectively. Must be in the form of $16\times n+2$. These two parameters will significantly affect the accuracy and computation time of the simulation. Usually, they should be larger than 146.
difmax, decay	used in the adaptive grid. We desire the grid to be not very coarse in some regions, so smaller numbers are preferred for L/UL simulation.
icmod	Asperity contact model: **1**=GW model; **2**=elastic-plastic model. We suggest using the GW model here.
gldht	glide height (m).
L/UL	**0**=disable L/UL simulation, calculate the steady state attitudes when static pitch and roll are imposed; **1**=simulate the load process; **2**=simulate the unload process.
kz1	estimated stiffness [N/m] at the slider's center in the vertical direction when the L/UL tab contacts the ramp. An accurate value is not required.
AccL/UL(m/ss)	initial vertical acceleration $[m/s^2]$ at the L/UL tab in the vertical direction. For loading, this value should be specified as the practical value. For unloading, you can specify it as zero or a very large value.
v(L/ULspeed,m/s)	quickly reached steady L/UL speed (m/s) at the tab in the vertical direction.
N_Sta	number of the suspension state [2] (2 ≤ **N_Sta** ≤5).
N_Par	number of parameters. Here, it's fixed at 4.

OutPr5 0=no pressure profile output; 1=output pressure profiles at the specified times.

p@t1(ms), p@t2, p@t3, p@t4 output pressure profiles at these times [ms] if **OutPr5** is equal to 1.

S.pitch, S.roll static pitch (PSA) and roll (RSA) [rad]. These two parameters significantly affect the L/UL process.

I_ey, I_ydst composite elastic modulus and yield strength [Pa] used in calculating slider/disk impact if the clearance between the slider and disk at some point is less than zero.

I_rad radius [m] of the impact region. A small value is used for new sliders, and a large value is for burnished sliders [8].

Suspension states. There are at least two states of the suspension in the L/UL process. The first is the free state, in which the suspension parameters are not required. In all other states, you need to specify the parameters of the suspensions. We use the suspension force applied on the slider and the force applied by the ramp to determine the suspension states during the L/UL process. Following are some examples.

a) Integrated suspension without a load dimple.

N_Sta=2,

f21=100, and f22=-100,

specify a **stiffness matrix**

b) Suspension with a dimple and without limiters

N_Sta=3,

State 2: Dimple is closed.

f21=100, and f22=-f_{dimple}, f_{dimple} is the dimple pre-load (gram).

State 3: Dimple is separated.

f31=-$\mathbf{f_{dimple}}$, and f32=-100

Specify a **stiffness matrix** for each state.

c) Suspension with a dimple and limiters. If the limiters are closed or separated at the same time, then, we have

N_Sta=4,

State 2: Dimple is closed, and limiters are open.

f21=100, and f22=-$\mathbf{f_{dimple}}$. $\mathbf{f_{dimple}}$ is the dimple pre-load (gram)

State 3: Dimple separates, and limiters are open.

f31=-$\mathbf{f_{dimple}}$, and f32=-$\mathbf{f_{limiter}}$. $\mathbf{f_{limiter}}$ is the force that makes the limiters close. We can approximately calculate it from equation

$\mathbf{f_{limiter}}=\mathbf{f_{dimple}}+k_f$*limiter gap.

[e.g. **2e-3+(21.9*50e-6)/9.81*1000=0.112** gram]

where k_f is the flexure stiffness, which is calculated by applying a force at the slider's center in the vertical direction and calculating the displacement at the center when the dimple is open and the L/UL tab is fixed in the vertical direction.

State 4: Dimple separates, and limiters are engaged.

F41=-$\mathbf{f_{dimple}}$, and f42=-100

Specify a **stiffness matrix** for each state.

The stiffness matrices. In each state, we have a different 4x4 stiffness matrix, which is calculated from FE models. In each state, by sequentially applying a force at the L/UL tab, slider center in the Z direction, and pitch and roll moments, one can obtain the flexibility matrix by calculating the displacements at the tab and the slider center in the Z direction, and the slider pitch and roll, respectively. Inverting the flexibility matrices, we obtained the stiffness matrices. The coordinate system is defined as shown in Fig. 1. The suspension used in examples 1 and 3 is similar to the one shown there. The point on the L/UL tab has a small offset in the Y direction.

4.3 Output file ***nload.dat***

This file contains thirteen columns:

Column	Contents
1	time (s)
2	Displacement at the L/UL tab (m)
3	Force applied on the slider (F_S) (gram)
4	Force applied by the ramp (F_L)(gram)
5	Displacement at the slider's center (m)
6	n/a
7	Normalized X-coordinate of the positive bearing force center.
8	Normalized Y-coordinate of the positive bearing force center.
9	Normalized X-coordinate of the suction force center
10	Normalized Y-coordinate of the suction force center
11	Minimum clearance (m)
12	X coordinate of the point on the slider with the minimum clearance (m)
13	Y coordinate of the point on the slider with the minimum clearance (m)

4.4 Other output files

The *lduldpar.out* file contains some parameters that are defined in the *dynamics.def* file. The *preshx.dat* files (*x*=1~4) contain the time and air bearing force at the time the pressure profiles are saved to the files *pressx.dat*. The data saved in these files can be displayed by the post-processing programs, such as *pressur1.m*, *pressur5.m*. In the PC version, the *load.dat* file has been changed into the *wload.dat* file, and the *contact1.dat* file has been changed into the *impact.dat* file..

5. Post-processing and examples

There are fourteen MATLAB programs for post-processing. The *rail2d.m, rail3d.m, history.m* and *p3d.m* files have been described in report [1]. The other programs are described below, where nt1 is the starting point number of the time histories, nt2 is the ending point number of the time histories. nt1=0 is the same as nt=1, and nt2=0 is the same as setting nt2 to the largest point number of the time histories. np is the point number of interest on the air bearing surface of the slider. np=0~5. Using np=0, we specify the point as the center of the trailing edge at the mean plane level. The air bearing surfaces of the slider used in the examples are shown in Fig. 2.

Name	command	Examples	descriptions
force1g.m	force1g(nt1,nt2)	Fig.3a	Displays the resultant air bearing force and its positive and negative components in one figure, in gram units.
force1n.m	force1n(nt1,nt2)	Fig.3b	Displays the resultant air bearing force and its positive and negative components in one figure, in Newton units.
Forc5c.m	forc5c(nt1,nt2)	Fig.4	Displays the resultant air bearing force, its positive and negative components, suspension force applied on the slider's center, and the ramp force applied by the ramp, in one figure.
Force.m	force(nt1,nt2)	Fig. 5	There are four figures arranged as

			Bearing forces Bearing force center Asperity contact force Impact force
frcdsp6.m	frcdsp6(nt1,nt2)	Fig.6	There are six figures arranged as Air Bearing Forces Normalized bearing force center Normalized force center in X Normalized force center in Y Displacement Air Bearing and L/UL forces
displace.m	displace(nt1,nt2,'Comment line 1',' Comment line 2',' Comment line 3',' Comment line 4')		
		Fig.7	There are five figures arranged as Comment lines Displacement Nominal FH Minimum clearance Roll Pitch
fly4p.m	fly4p(nt1,nt2)	Fig.8	There are six figures arranged as FH at point 1 FH at point 2 FH at point 3 FH at point 4 Pitch Roll
flyzpr5.m	flyzpr5(np,nt1,nt2)	Fig.9	There are five figures arranged as Parameters Disk track Displacement at np FH at point np Pitch Roll
pressur5.m	pressur5	Fig.10	There are five pressure profiles arranged as Parameters at the end of the process at **p@t1** at **p@t2** at **p@t3** at **p@t4**
pressur1.m	pressur1(n)	Fig.11	Display of the air bearing pressure profile at a specified time n (n=1~4).

Acknowledgments

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Refernces

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2 Q. H. Zeng and D. B. Bogy, “A Simplified 4-DOF Suspension Model for Dynamic Load/Unload Simulation and Its Application,” Technical Report No. 99-003, Computer Mechanics Laboratory, U. C. Berkeley, February 1999.

3 Q. H. Zeng and D. B. Bogy, “Effects of Suspension Limiters on the Dynamic Load/Unload Process: Numerical Simulation,” Technical Report No. 99-002, Computer Mechanics Laboratory, U. C. Berkeley, February 1999.

4 Q. H. Zeng and D. B. Bogy, “Slider Air Bearing Designs for Load/Unlaod Applications,” Technical Report No. 98-009, Computer Mechanics Laboratory, U. C. Berkeley, June 1998.

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7 R. Grisso, S. Lu and D. B. Bogy, “CML Air Bearing Design Program (Version 4.0.17) and 32-bit Windows Interface,” Technical Report No. 97-013, Computer Mechanics Laboratory, U. C. Berkeley, 1997.

8 M. Suk and D. Gillis, “Effect of Slider Burnish on Disk damage During Dynamic Load/Unload,” *ASME Journal of Tribology*, Vol. 120, Apr. pp. 332-338, 1998.

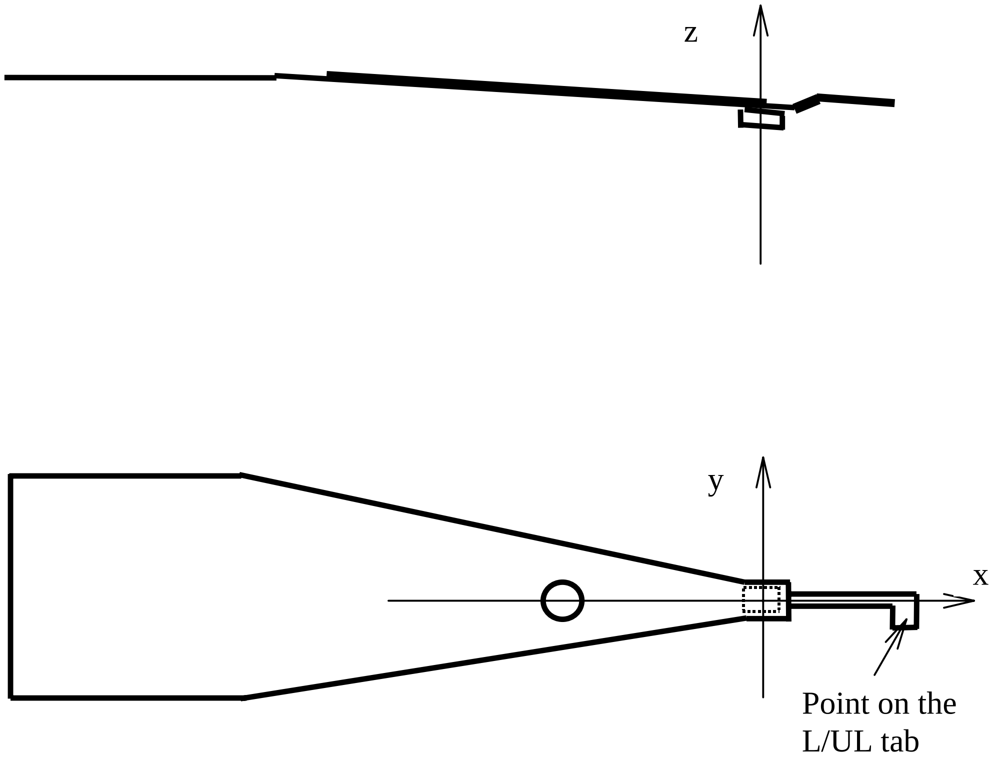
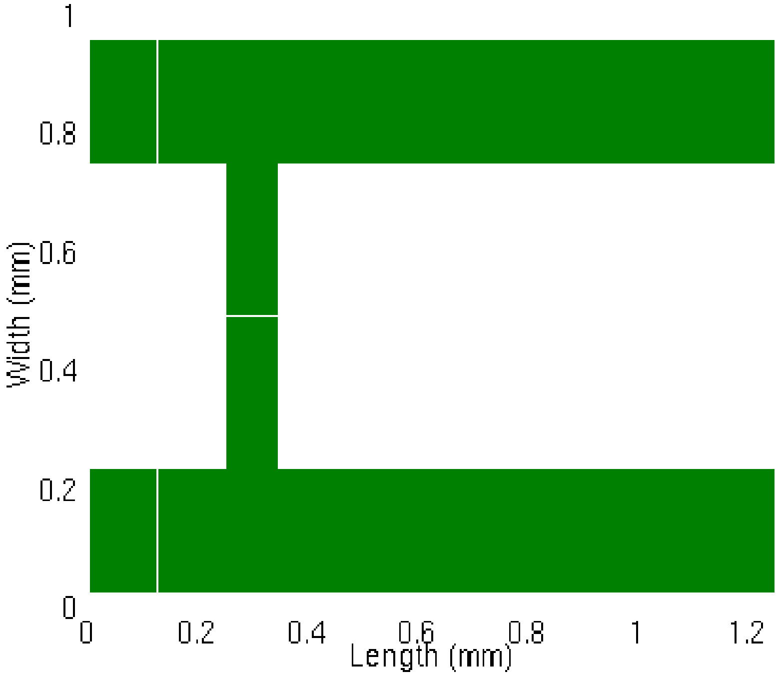
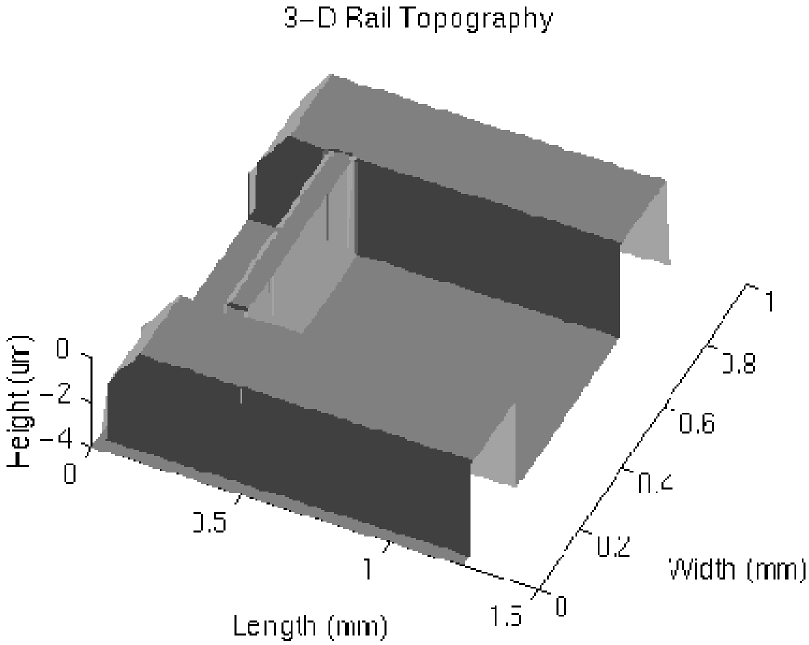


Fig. 1 Coordinate system used in calculating suspension stiffness matrices



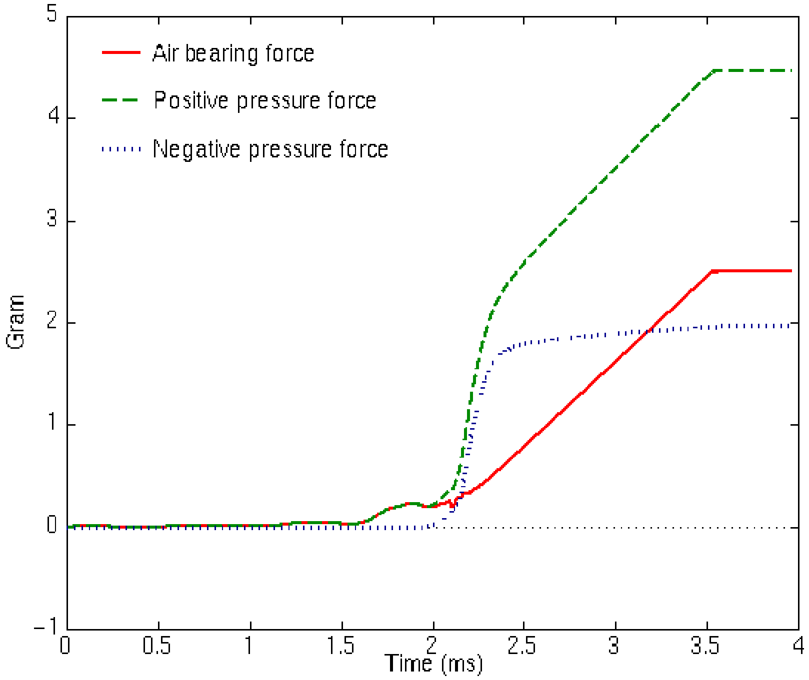
a) created by command ***rail2d***



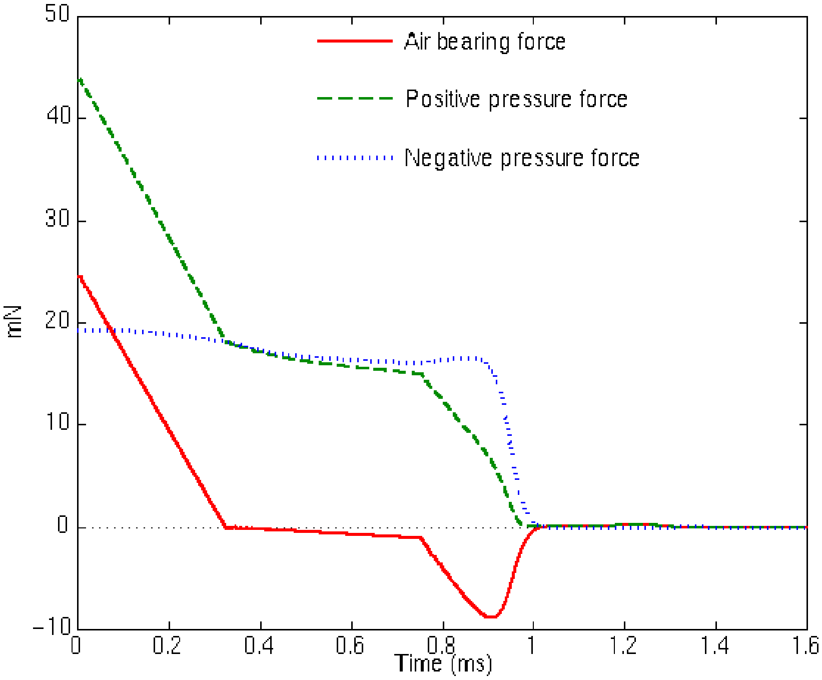
b)

c) created by command ***rail3d***

Figure 2 A slider used in the examples



a) (Example 1) created by command ***forc1g(0,4400)***



b) (Example 2) created by command ***forc1n(0,4000)***

Figure 3 Air bearing force history in Newton and gram units.

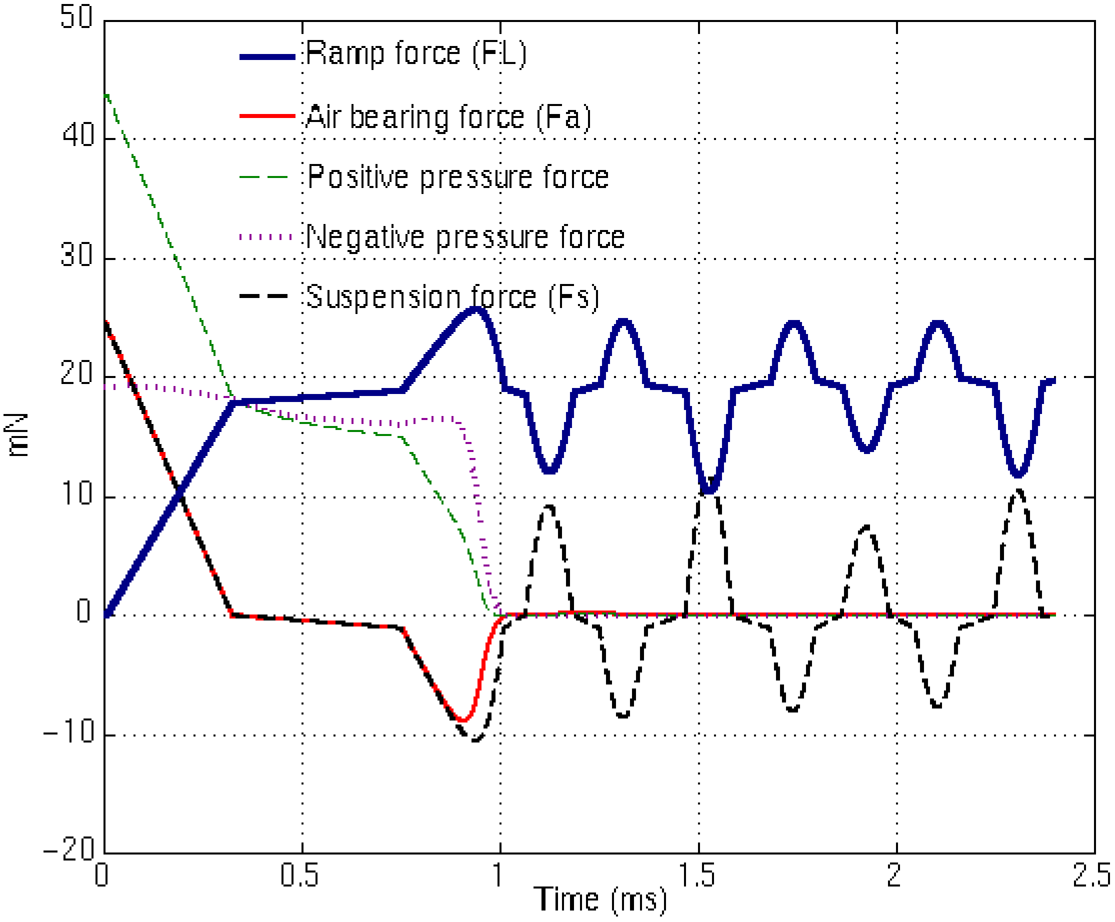
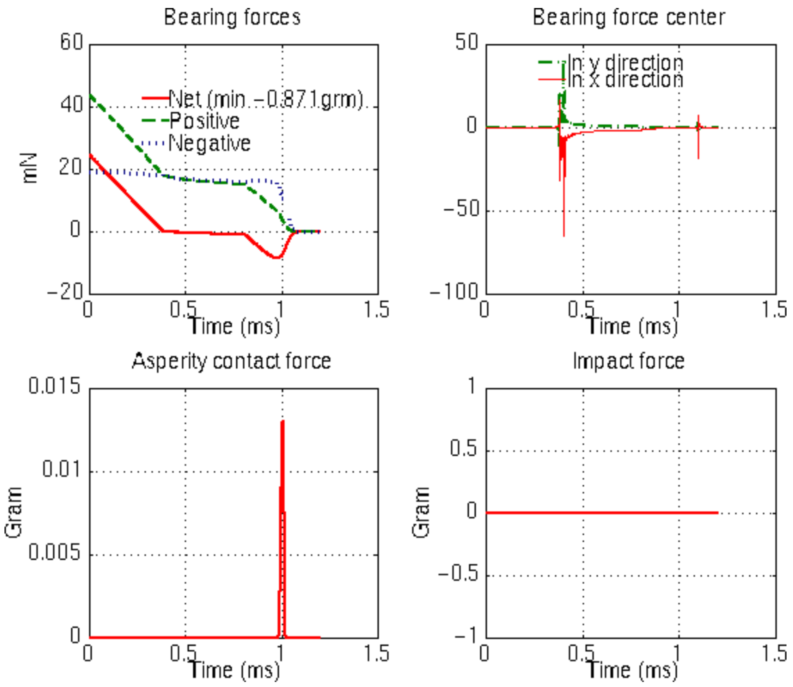
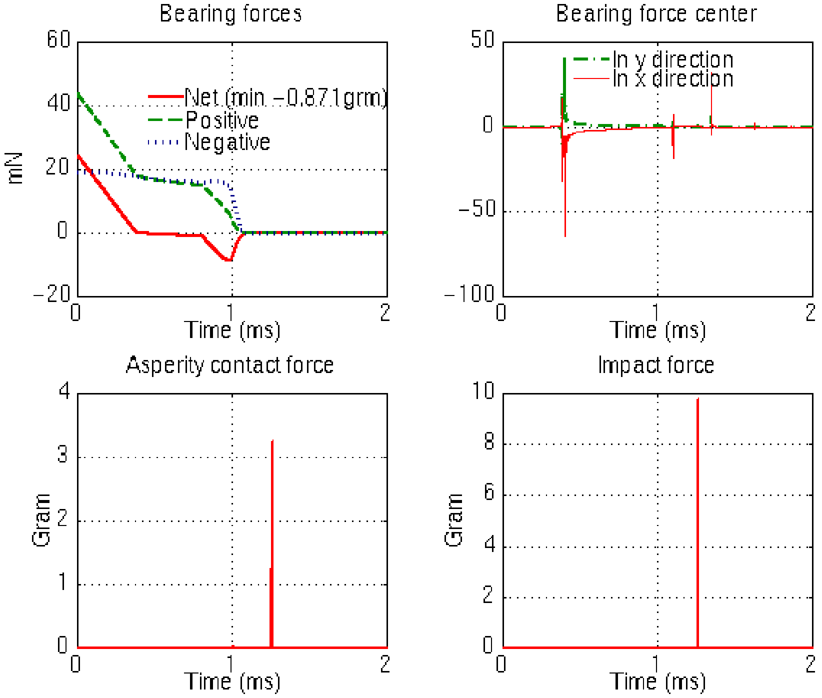


Figure 4 Force histories during the unload process

(Example2) created by command ***forc5c(0,6000)***



a) (Example3) created by command ***force(0,1200)***



b) (Example3) created by command ***force(0,2000)***

Figure 5 Air bearing force, its center, asperity contact force and impact force

(We can see that the slider contacts disk before and after the air bearing disappears)

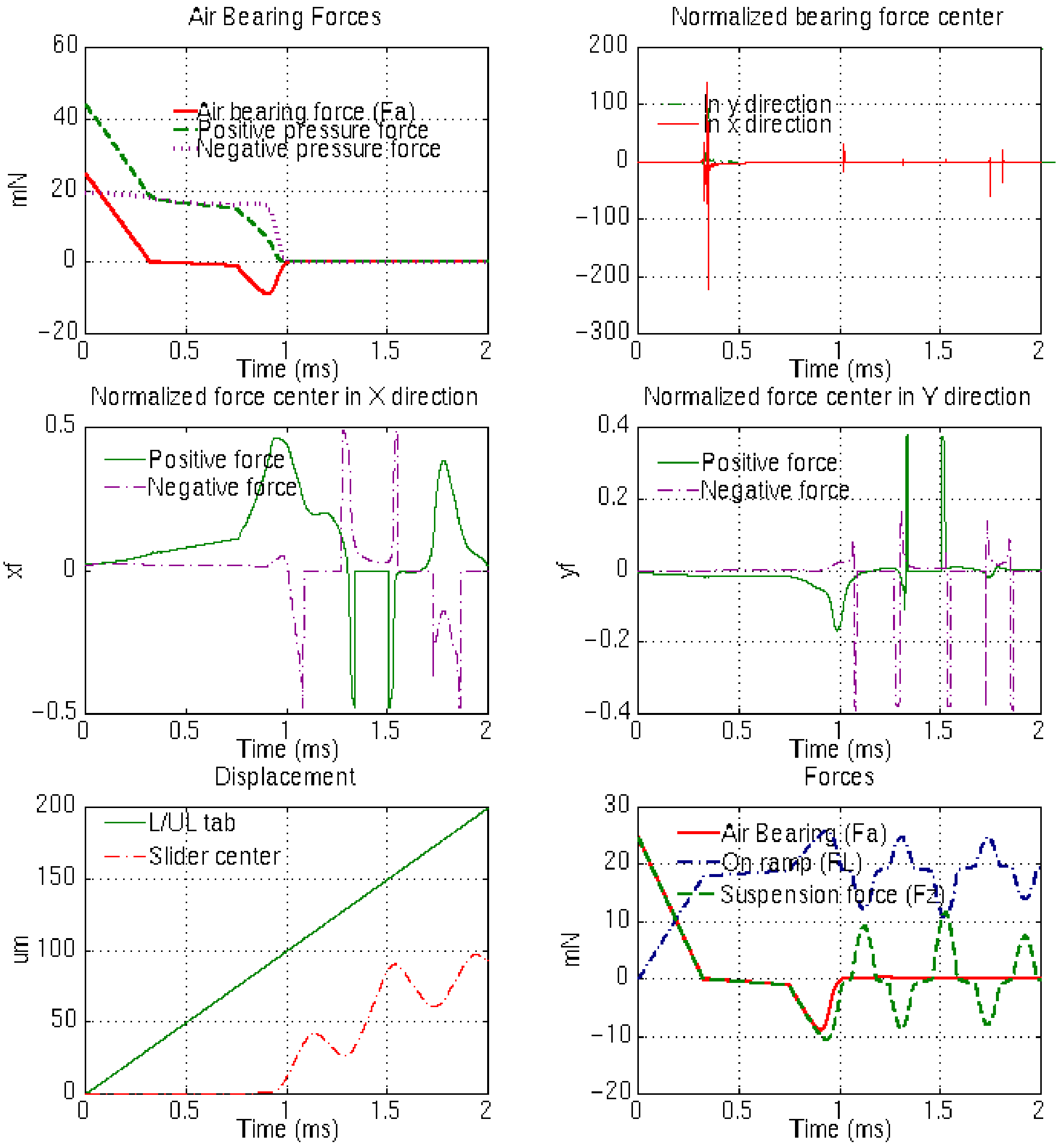


Figure 6 Force and displacement history during unload

(Example2) created by command ***frcdsp6(0,5000)***

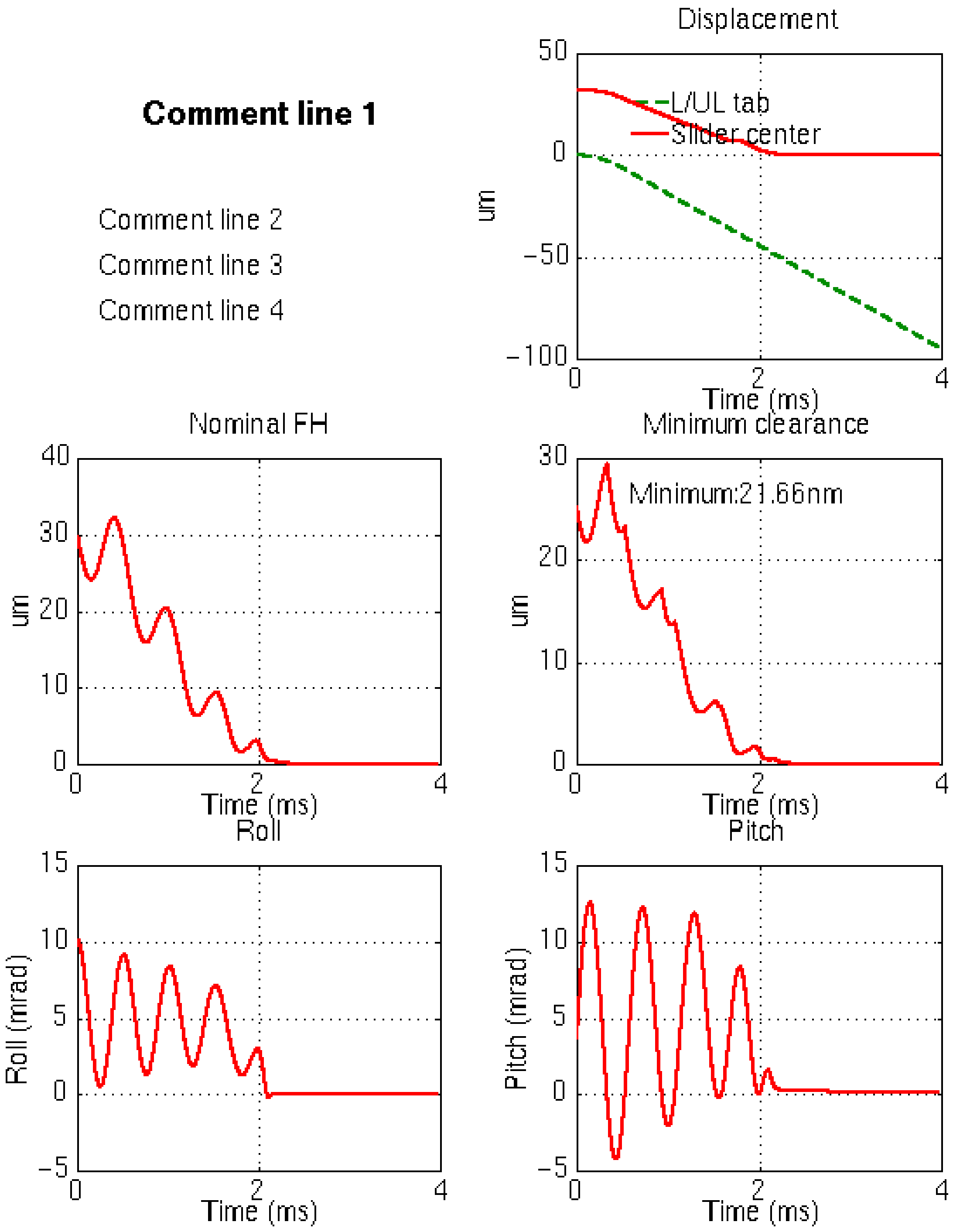


Figure 7 Displacement of the L/UL and flying attitude histories of the slider during load

(We can see that the minimum clearance (21.66 nm) is larger than zero. That means there is no contact between slider and disk)

(Example1) created by command ***displace(0,4400,'Comment line 1', 'Comment line 2', 'Comment line 3', 'Comment line 4')***

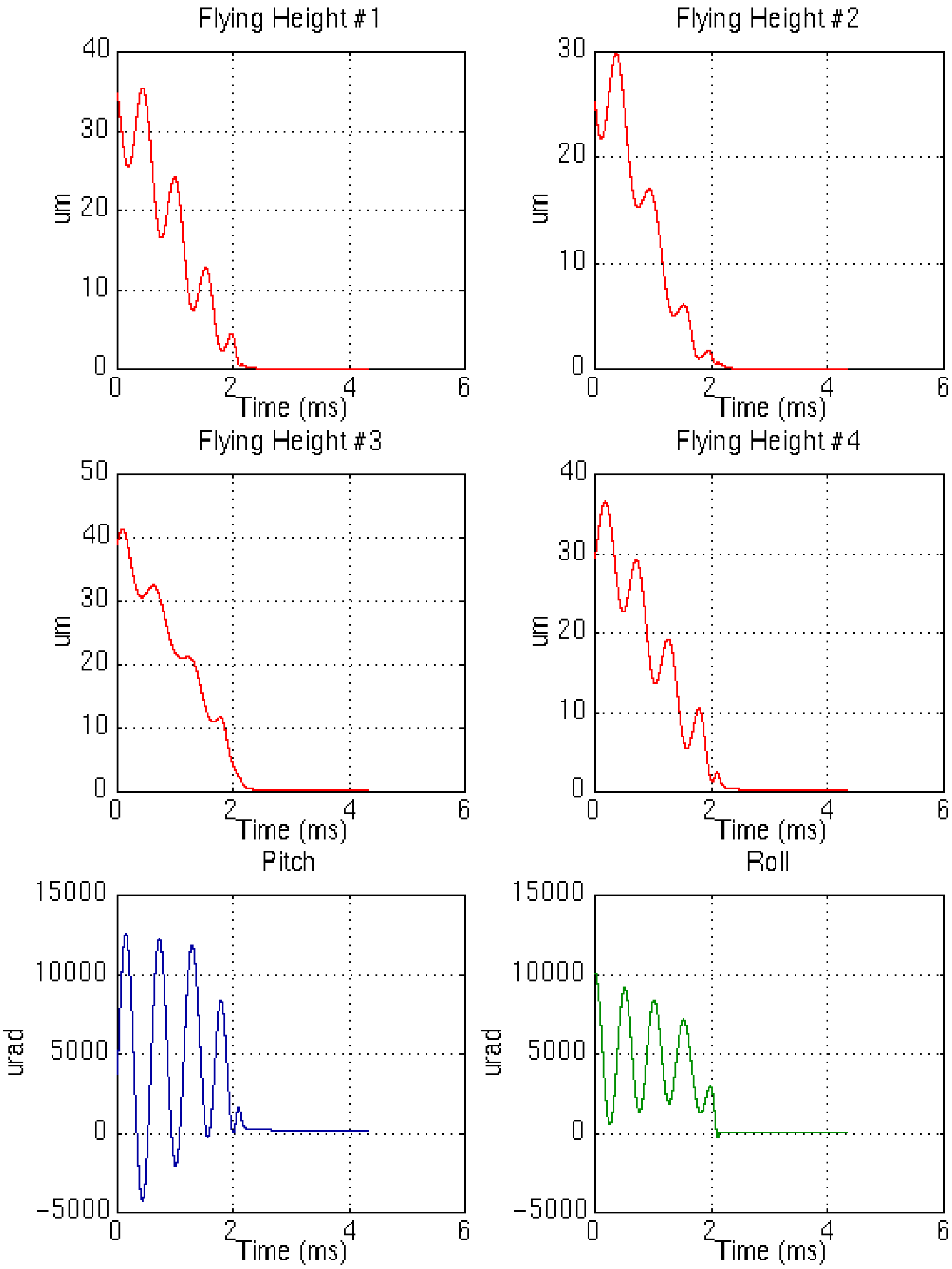


Figure 8 Flying heights at the force points, pitch and roll of the slider during the load process

(Example1) created by command ***fly4p(0,0)***

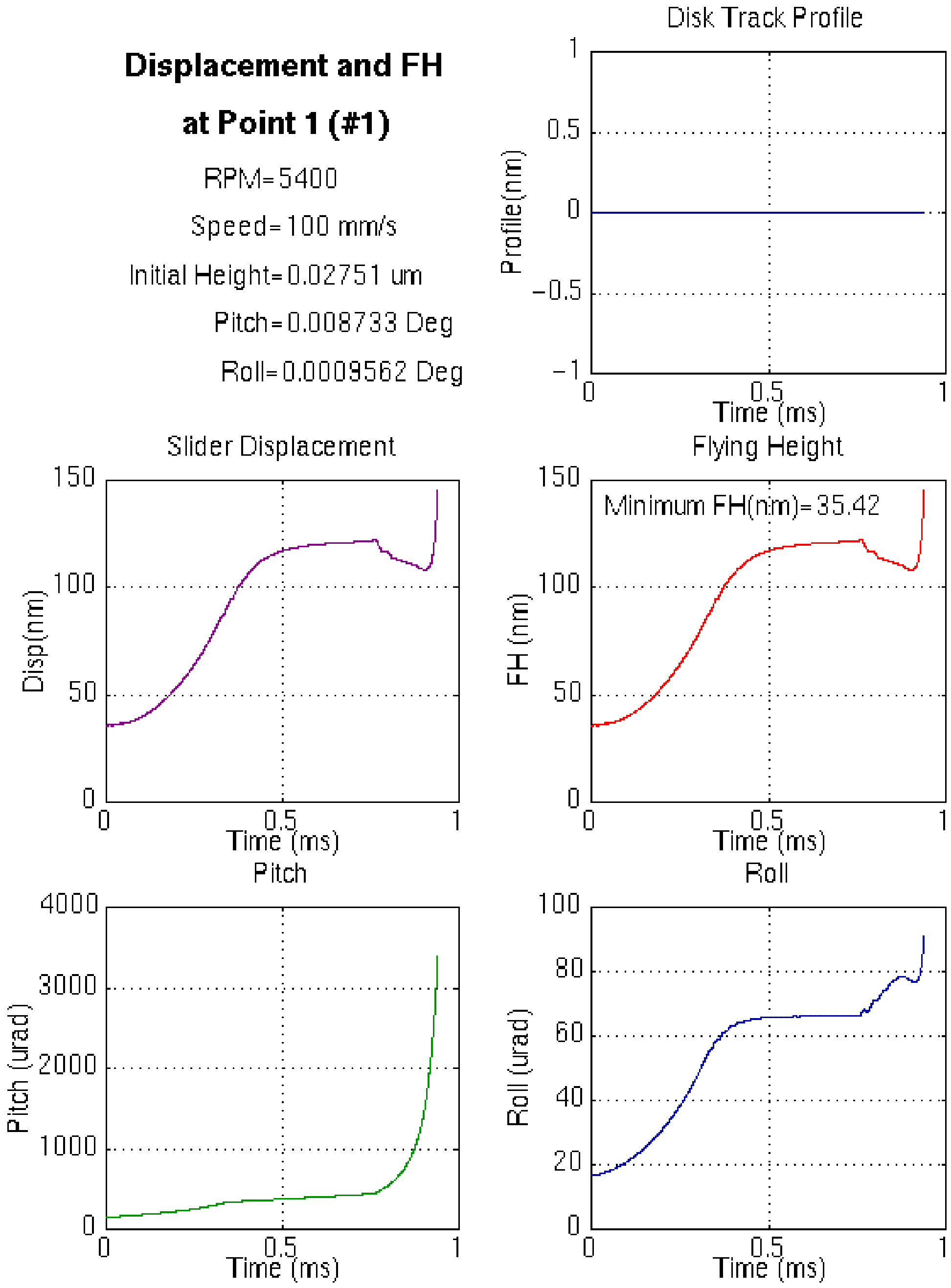


Figure 9 Flying attitude histories of the slider during the unload process

(Example2) created by command ***flyzpr5(1,0,2350)***

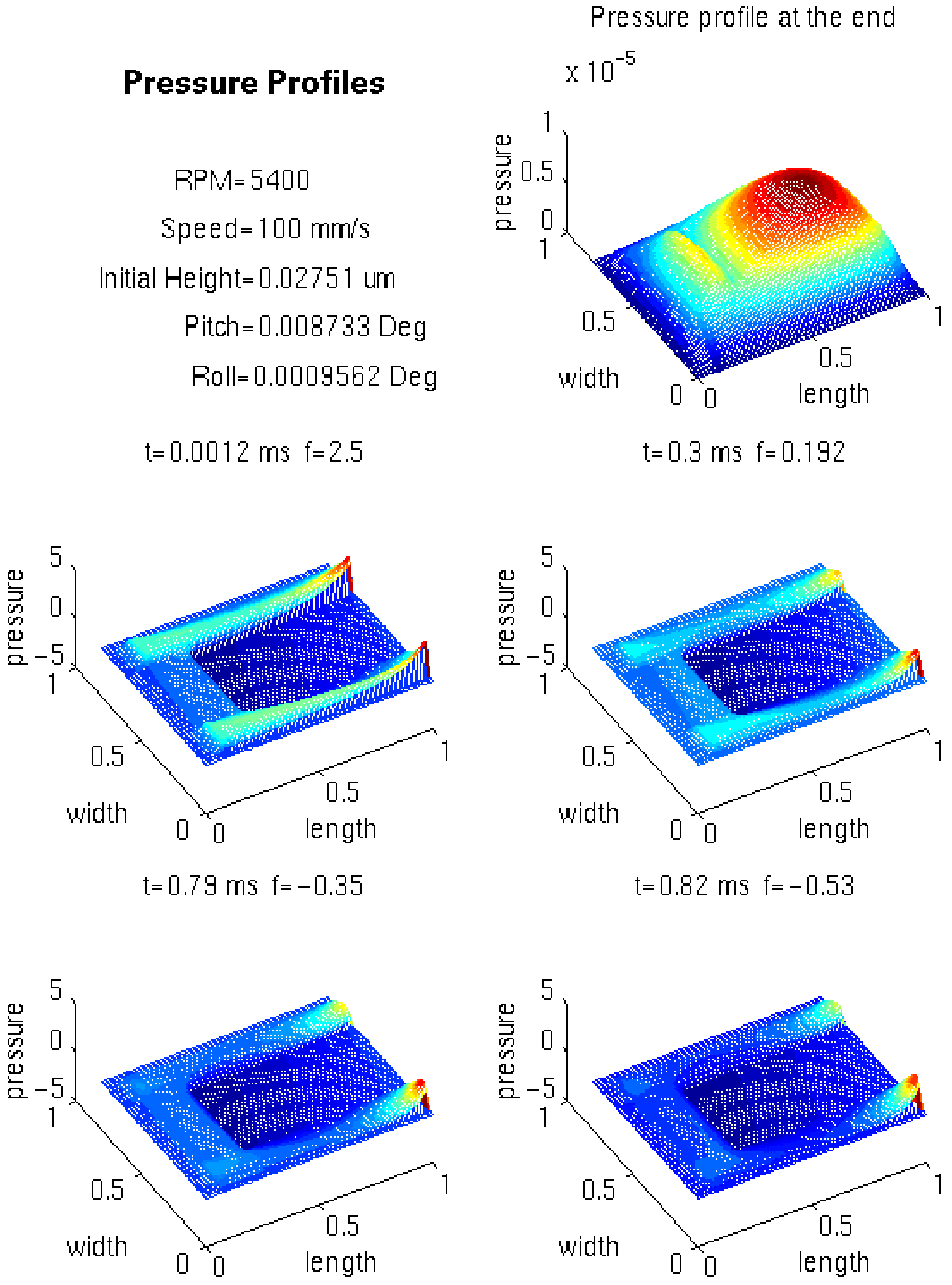


Figure 10 Air bearing pressure profile during unload

(Example2) created by command ***pressur5***

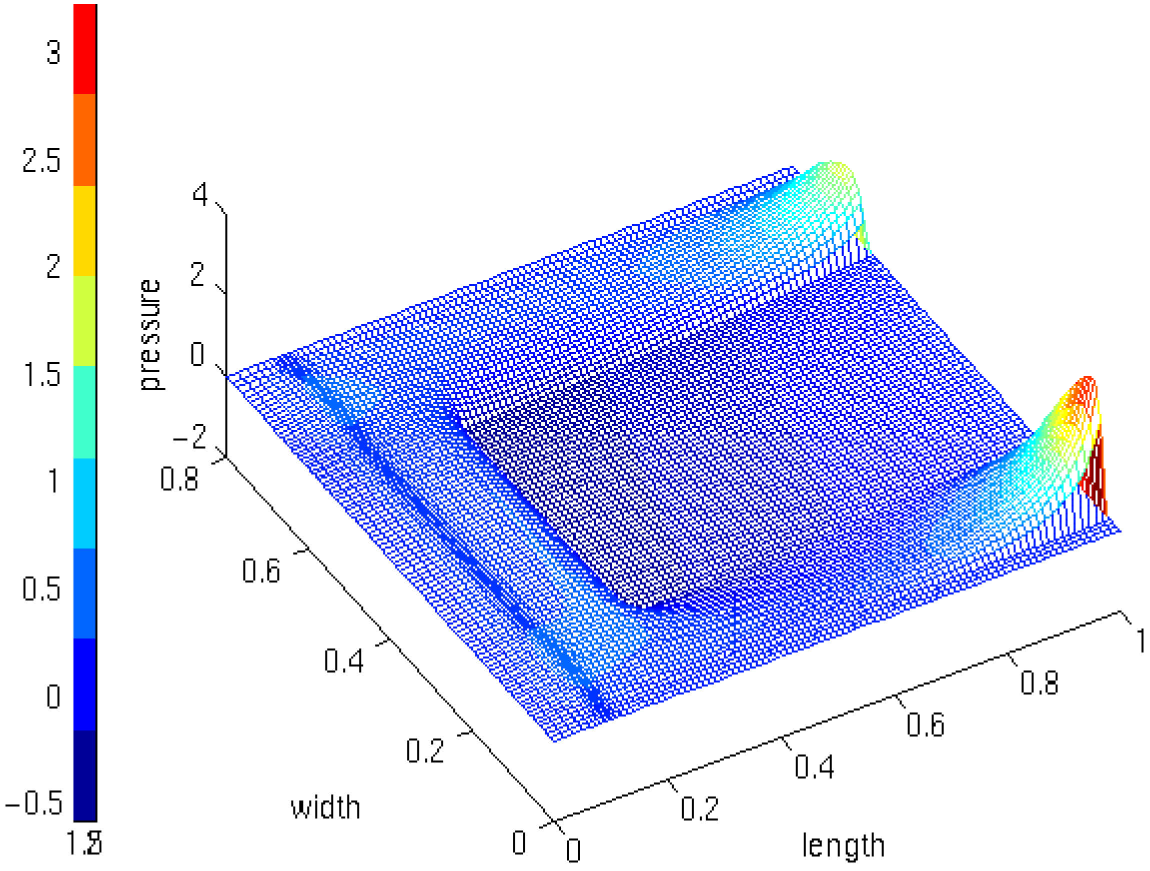


Figure 11 Air bearing pressure profile during unload at **p@t4** (0.83 ms)

(Example2) created by command ***pressur1(4)***