The CML Dynamic Load/Unload/Shock Simulator

(Version 5.1)

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1 Introduction

This report is a detailed manual for the new Load/Unload and Shock (L/UL/S) simulator developed at the Computer Mechanics Laboratory at the University of California, Berkeley. The response of the suspension-slider-disk system during events such as L/UL and shock is determined by the air bearing behavior as well as the structural response of the suspension and the disk. In this version of the L/UL/S simulator, the air bearing is modeled using the finite volume method as discussed by Lu (1997). The suspension modeling is done using the finite element method with the program taking the preassembled mass and stiffness matrices as inputs (see Bhargava and Bogy (2005)).

The new L/UL/S simulator has many improvements over the old L/UL simulator (Zeng and Bogy (1999)). These include:

1. Finite element modeling for the suspension. The L/UL/S simulator takes as inputs preassembled mass and stiffness matrices for the suspension. Since a full FE model for the suspension would be overkill, we suggest a technique of reducing the number of degrees of freedom of the system using Guyan reduction (Guyan (1965)) in ANSYS (ANSYS (2005)), which is a commercial finite element package.

2. Modeling of user defined ramp profiles, whereby load and unload velocities are calcualated automatically using the specified angular motion of the actuator.

3. Simulation of shock and vibration. In addition to simulating the L/UL process, the new simulator can also simulate shock and vibration. Shock is modeled as a half-sine/square wave acceleration pulse to the system, while vibration is modeled as a constant/decaying amplitude sinusoidal acceleration wave.

4. Improved elastic impact modeling. The impact model calculates the force on the slider when the fly-height at any point becomes negative. The new model discussed in (Bhargava and Bogy (2006)) is more robust and faster than the model used previously.

5. Inclusion of intermolecular forces. The L/UL/S simulator incorporates the intermolecular force model proposed by Gupta and Bogy (2004).

2 Installation

The file `LULSV51.zip` is a compressed zip file of the L/UL/S simulator and the pre and post processing files. Create the directory CML_DLULS in the root directory of a drive, eg. `c:\CML_DLULS` and copy `LULSV51.zip` into this directory. You can use Winzip to extract the files from the archive into the `CML_DLULS` directory, and thereby get the `LULSV51.exe` and five subdirectories (`mfiles, example1, example2, example3 and example4`.

To run a simulation, eg. `example1`, you should open a new DOS command prompt (`cmd`), change the directory to `c:\CML_DLULS\example1` (using `cd c:\CML_DLULS\example1`) and run the program `LULSV51.exe` from the parent directory (`..\LULSV51.exe`). To post process the results using the provided MATLAB subroutines, you will need to run MATLAB, change the current directory to `c:\CML_DLULS\example1` and set path to use the directory `c:\CML_DLULS\mfiles` (using `path(path,‘c:\CML_DLULS\example1’)`. Then you can use the m-files to display the results in MATLAB. eg. `force(0,0)`.

3 Procedure

1. Design the air bearing using the CML air bearing design program (CML (2006)). Export the rail.dat file for input to the L/UL/S simulator.

2. Create the dynamics.def input file. The easiest way to do this is to use the sample dynamics.def file and modify the desired parameters.

3. Find the steady state flying attitudes of the slider and create the grid. The following procedure suggested by Zeng and Bogy (1999) is recommended. Use the results from a static flyheight simulation using the CML air bearing design program as initial values

to run a "no L/UL/S" simulation (`L/UL=0`, `shmod=0` in the *dynamics.def* file) with adaptive gridding turned on (`iadpt=1`, `ioldgrid=0`) and using `dt=1e-7`, `tf=2e-3`. The steady state flying attitudes can be obtained using the post processing programs to view the attitude histories. The grid created will be saved in the files *x.dat* and *y.dat*. Now run the desired simulations with adaptive gridding turned off using the previously generated grid files.

4. Perform the L/UL or shock/vibration simulations.

5. Analysis of the results can be done using the provided MATLAB postprocessing routines.

4 Suspension model

This section discusses the method for obtaining the mass and stiffness matrices for the suspension-slider system. The procedure described here uses the finite element model of the suspension in ANSYS. It is up to the user to export stiffness and mass matrices from other finite element software. Typically suspension models have a very large number of degrees of freedom, and solving such large models at each time step for a large number of time steps is very expensive as well as unnecessary. Hence we reduce the total number of degrees of freedom of the suspension using a procedure known as Guyan reduction, which is available in ANSYS as the substructuring option. In the method we discuss here, we will be able to reduce the suspension model as well as obtain the mass and stiffness matrices in one single step. Since the suspension model is inherently nonlinear, due to contacts at the dimple-flexure and the limiters, we will obtain the mass and stiffness matrices for the free state (ie when the dimple is open and limiters are not in contact) of the suspension only, and implement the contacts on top of the matrices using additional contact elements in the L/UL/S simulator itself. All contacts are modeled as node to node contacts. The following procedure discusses how to reduce the finite element model and obtain the mass and stiffness matrices:

1. Open the suspension model (**.db, *.inp* etc) in ANSYS. Enter the solution mode.
2. Unselect all contact elements
3. Identify node numbers corresponding to our primary DOF of interest. These are:
   (a) The six DOF for the attitude of the slider (3 displacements and 3 rotations, see Figure 3)
   (b) DOFs for the dimple-flexure, and limiters which will be used for contact elements
   (c) DOF for the L/UL tab. This will be used to implement contact with the ramp, and can also be used to monitor the motion of the load beam during the event of shock.
4. Define the DOFs identified above as master DOFs using the `M` command.
5. Define the total number of master DOFs using the `TOTAL` command (a total of 250 MDOFs are recommended, ie `TOTAL,250`).
6. Define a new substructuring analysis. Set the analysis options to generate Stiffness and Mass matrices along with load vector and matrix printouts enabled.
7. Redirect output from the screen to a file *SuperNNN.txt* using the `/OUTPUT` command, where NNN is the total number of master DOFs defined using the `TOTAL` command.
8. Run the substructuring analysis
9. After the analysis save the listing of the master DOF set using the `NSEL,S,M,,ALL` and `NLIST` commands. Save the output from the `NLIST` command to a file *coordsNNN.txt*.

10. Now use the fileprocessor program using the command *fileproc.exe NNN* in the same directory as the files *superNNN.txt* and *coordsNNN.txt* to generate the files *mass.txt*, *stiffness.txt* and *coords.txt*.

The generated stiffness, mass and coordinate data files can be used as inputs to the L/UL/S simulator.

5 Input files

5.1 rail.dat

The rail.dat file defines the rail shape and the air bearing surface. This file is generated by the CML Air Bearing Design Program (CML (2006)).

5.2 dynamics.def

The dynamics.def file is the primary parameter input file to the L/UL/S simulator. Most of them are the same as described in Chen et al. (1998). The parameters which are important, different or additional are discussed here.

5.2.1 Problem definition

`f0:` suspension normal load (kg)

`xf0(/xl), yf0(/yl):` normalized coordinates of the load point. They must be same as xg and yg.

`rpm:` disk revolutions per minute

`dt:` time step (s). A value of 1e-7 is recommended for all simulations.

`ra:` radius of the *reference* position (see Figure 1).

5.2.2 Suspension

`iact`: 0 = no actuator; 1 = inline actuator. Always keep `iact` = 1.

`xact`: length of actuator arm [m] (see Figure 1).

`dact`: angular position of actuator with respect to the reference position [rad] (see Figure 1).

`vact`: angular velocity of actuator, positive velocity indicates that slider moves from OD to ID [rad/s].

`ske`: the skew angle (degree) at the specified reference radial position (see Figure 1).

5.2.3 Initial Flying Condition

`hm, hp, hr, dx, dy and yaw`: the initial nominal flying height (m), pitch, roll (rad), x, y displacements (see Figure 3) and yaw (rad) of the slider. For loading, these values are not used.

5.2.4 Grid Control

`iadpt`: 1 = use adaptive grid to generate the grid; 0 = disable grid generation.

`ioldgrid`: 1 = use the old grid saved in the `x.dat` and `y.dat` files; 0 = use adaptive grid.

`nx, ny`: grid size in the x and y directions, respectively. Must be in the form of $16 \times n + 2$. Usually, these should be larger than 146.

`difmax, decay`: used in the adaptive grid. See Zeng and Bogy (1999) for more information.

5.2.5 Asperity Contact

`icmod`: Asperity contact model: 1=GW model; 2=elastic-plastic model. We suggest using the GW model here.

`gldht`: glide height (m).

5.2.6 Dynamic Load/Unload

`L/UL`: 0=disable L/UL simulation; 1=simulate the load process; 2=simulate the unload process.

`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 isequal to 1.

`S.pitch, S.roll`: static pitch (PSA) and roll (RSA) [rad].

`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.

`suspsz`: Total number of DOFs in the suspension

`dofux, ..., dofrotz`: DOF numbers corresponding to slider x, y, z displacements and x, y, z rotations (roll, pitch and yaw).

`doftab`: DOF number corresponding to L/UL tab z-displacement.

`dtfac`: Time step reduction factor during contact. It is recommended this value be kept at 10 (i.e. the time step will be reduced by a factor of 10, when contact occurs).

For quicker simulations a value of 1 may be used with some loss of accuracy during contact.

`nocele`: Number of contact elements to be defined. $nocele = \# \, of \, limiter \, contacts + 1 \, (for \, dimple)$.

`dofcu, dofcd, constat, preload`: DOF number corresponding to nodes above (`dofcu`) and below (`dofcd`) contact element. `constat` indicates whether the contact elements are closed (1) or open (0) at the beginning of the simulation. `preload` indicates the preloading of the contact element. This can be used to adjust the dimple preload [mN] for the dimple contact element (otherwise leave at 0).

`nrp, theta, z`: The description of the ramp profile. `nrp` indicates the number of ramp profile points. The ramp profile will be linearly interpolated between these points. `theta` indicates the angle [rad] measured from the reference position and z indicates the height of the ramp [mm] (see Figure 4 and Figure 5).

5.2.7 Disk Modeling

`idmod`: 1 is disk modeling on and 0 indicates disk is not to be modeled.

`disksize`: Size of the disk model. The size of the default disk model is 247.

`nsnodes`: Number of radial nodal locations.

`zdof, rotx, roty`: DOF numbers for z-displacement and x,y rotations for nodes from the OD to the ID on the x-axis. A second order linear interpolant will be used to calculate disk motion between these radial locations.

5.2.8 Shock

`shmod`: Shock mode: 0 noshock, 1 half-sine shock pulse, 2 square-wave shock pulse, 3 constant magnitude sinusoidal acceleration field, 4 decaying sinusoidal acceleration field.

`sttime`: Acceleration pulse start time [s]

`pulsewid`: Pulse width of the acceleration pulse/wave [s].

`magnitude`: Magnitude of acceleration [G].

`tconst`: Time constant for `shmod = 4`.

5.3 mass.txt, stiffness.txt, coords.txt

The first two files are the mass and stiffness matrices for the suspension. The third file contains the coordinate locations for the nodes as well as DOF information. The columns in *coords.txt* are x, y and z coordinates of the DOFs, and the type of DOF (1,2,3: x,y,z displacement; 4,5,6: x,y,z rotation, see see Figure 2). These files can be automatically generated from ANSYS using the procedure in the previous section. The user can also choose to generate these files using other finite element packages.

6 Output files

This section discusses additional time-history output files generated by the L/UL/S simulator.

6.1 attitude.dat

This file contains the time [s], the displacements of the 6 DOF of the slider [mm, rad], as well as velocities [mm/s, rad/s]and accelerations [mm/s/s, rad/s/s] corresponding to these 6 DOF (see Figure 3).

6.2 cestatii.dat

Time [s], and the contact status, contact spacings [mm] and contact force [mN] for each contact element.

6.3 cpressures.dat

Time [s], maximum contact pressure [atm] and maximum impact pressure [atm].

6.4 imf.dat

Time [s], intermolecular force [mN], resultant intermolecular moments in pitch and roll directions about slider center [mN mm].

6.5 lultab.dat

Time [s], ramp contact status, tab displacement [mm], ramp contact force [mN], angle dact [rad] (see Figure 1) and the ramp height at dact [mm].

6.6 shock.dat

Time [s], acceleration magnitude, disk z-displacement [mm], disk 'roll' [rad] and disk 'pitch' [rad].

7 Post-processing

All of the post processing programs available for use with the previous version of the CML L/UL Simulator (Zeng and Bogy (1999)) can still be used with the L/UL/S Simulator. However some of the old Matlab subroutines have been modified and certain new ones have been added, which are discussed in this section.

7.1 displaceLUL.m

Usage: displaceLUL(<n1>,<n2>,<'Comment1'>,<'Comment2'>,<'Comment3'>,<'Comment4'>) where <n1> and <n2> indicate the range of the data to be plotted. Setting <n1> and <n2> will plot the entire time history data.

This function was previously available as *displace.m* in the previous version of the L/UL simualtor. However it can still be used to plot L/UL displacements. The output from the command displaceLUL(0,0,'Loading Process','Vlul = 8 rad/s','','') for example 1 is shown in Figure 6. The various quantities plotted are: a) absolute displacements of L/UL tab and slider centre, b) the nominal FH, c) the minimum clearance, d) the pitch and e) the roll.

7.2 displaceSHOCK.m

Usage: displaceSHOCK(<n1>,<n2> where <n1> and <n2> indicate the range of the data to be plotted. Setting <n1> and <n2> will plot the entire time history data.

A modification of the function *displaceLUL.m*, this function can be used to plot the slider attitude for shock and vibration simulations. The output from the command displaceSHOCK(0,0) for example 3 is shown in Figure 7 and for example 4 in Figure 8. The various quantities plotted are: a) the acceleration profile, b) absolute displacements of load beam, slider centre (flexure) and disk, c) the nominal FH, d) the minimum clearance, e) the pitch and f) the roll.

7.3 force.m

Usage: force(<n1>,<n2>) where <n1> and <n2> indicate the range of the data to be plotted.

This function has been retained from the previous version of the L/UL simulator. The output from the command force(0,0) for example 2 has been plotted in Figure 9 and for example 3 in Figure 10. The various quantities plotted are: a) the air bearing forces (positive, negative and net), b) the bearing force center, c) the asperity contact forces and d) the elastic impact forces.

7.4 cestat.m

Usage: `cestat(<n1>,<n2>)` where `<n1>` and `<n2>` indicate the range of the data to be plotted.

This function plots the spacing and contact forces corresponding to the contact elements defined for the suspension. These are the dimple-flexure and the limiters. Figure 11 plots the contact element status for example 2 (unloading) generated using the command `cestat(0,0)`, and Figure 12 plots for example 3. The various quantities plotted are: a) dimple spacing, b) dimple contact force, c) limiter spacing and d) the limiter contact forces.

7.5 lulbehav.m

Usage: `lulbehav(<n1>,<n2>)` where `<n1>` and `<n2>` indicate the range of the data to be plotted.

This function plots various quantities relating to the L/UL behavior. The output from the command `lulbehav(0,0)` for example 1 have been plotted in Figure 13. The quantities plotted are: a), b) absolute displacements of the ramp (profile under the L/Ul tab) and the L/UL tab as a function of time and actuator angle, c) the ramp contact force, d) angular displacement of the actuator, e) velocity of the L/UL tab and f) the acceleration of the L/UL tab.

7.6 actmot.m

Usage: `actmot(<n1>,<n2>)` where `<n1>` and `<n2>` indicate the range of the data to be plotted.

This function plots various quantities relating to the actuator motion. The output from the command `actmot(0,0)` for example 1 have been plotted in Figure 14. The quantities plotted are: a), b) absolute displacements of the ramp (profile under the L/Ul tab) and the L/UL tab as a function of time and actuator angle, c) the ramp contact force, d) angular displacement of the actuator, e) velocity of the L/UL tab and f) the acceleration of the L/UL tab.

Acknowledgment

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References

ANSYS. *ANSYS 8.1 Documentation*, 2005.

P. Bhargava and D. B. Bogy. Numerical simulation of load/unload in small form factor hard disk drives. Technical Report 2005-011, CML, University of California, Berkeley, 2005.

P. Bhargava and D. B. Bogy. A new boundary element method based quasi-static elastic contact model for head disk contact. Technical Report 2006-010, CML, University of California, Berkeley, 2006.

L. Chen, Y. Hu, and D. B. Bogy. The cml air bearing dynamic simulator (version 4.21). Technical Report 1998-004, CML, University of California, Berkeley, 1998.

CML. *CML Air Bearing Design Program Manual*, 2006.

V. Gupta and D. B. Bogy. Effect of intermolecular forces on the static and dynamic performance of air bearing sliders: Parts i, ii. Technical Report 2004-001,002, CML, University of California, Berkeley, 2004.

R.J. Guyan. Reduction of stiffness and mass matrices. *AIAA Journal*, 3:310, 1965.

S. Lu. *Numerical Simulation of Slider Air Bearings*. PhD thesis, University of California, Berkeley, 1997.

Q. Zeng and D. B. Bogy. The cml dynamic load/unload simulator (version 421.40). Technical Report 1999-005, CML, University of California, Berkeley, 1999.

8 Figures

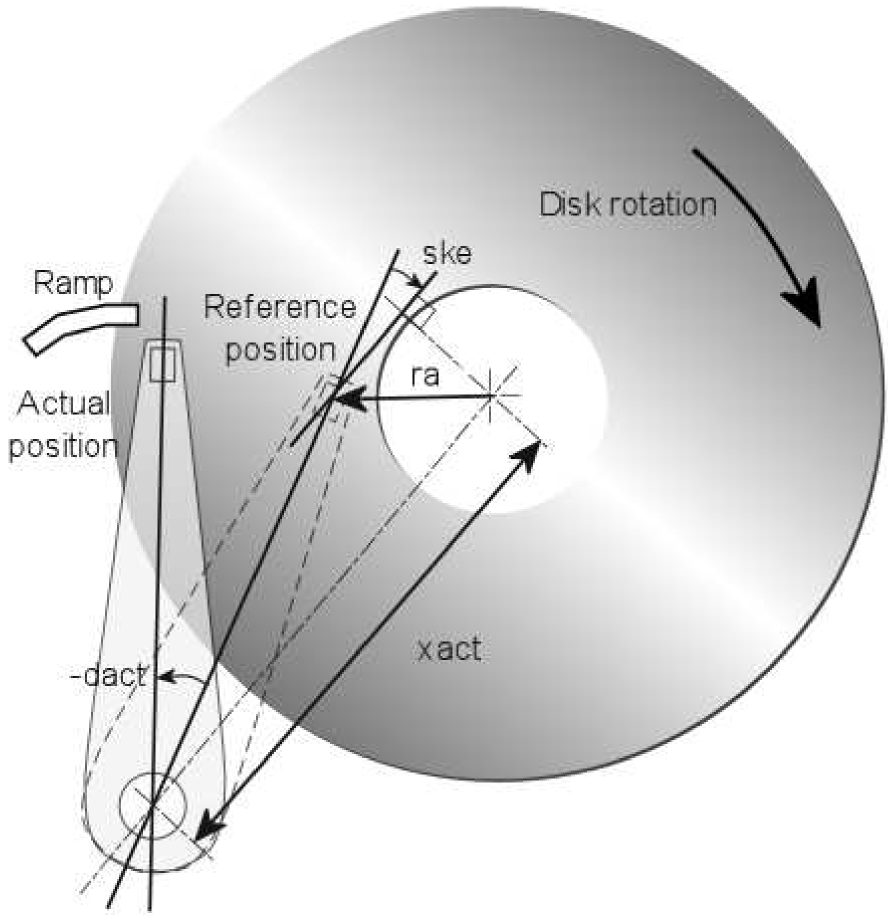

Figure 1: Actuator nomenclature

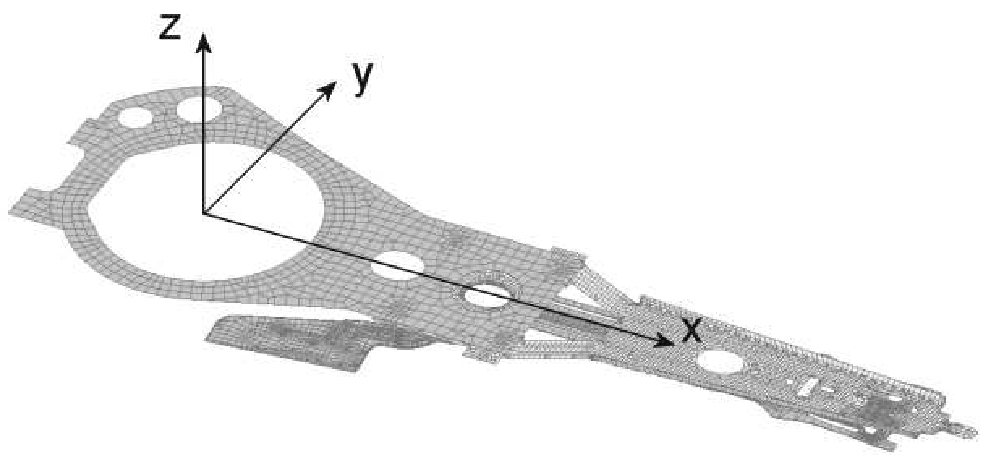

Figure 2: The suspension coordinate system

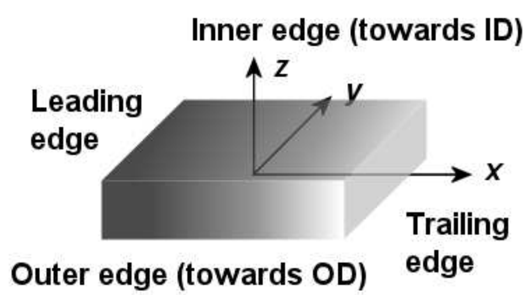

Figure 3: The slider coordinate system

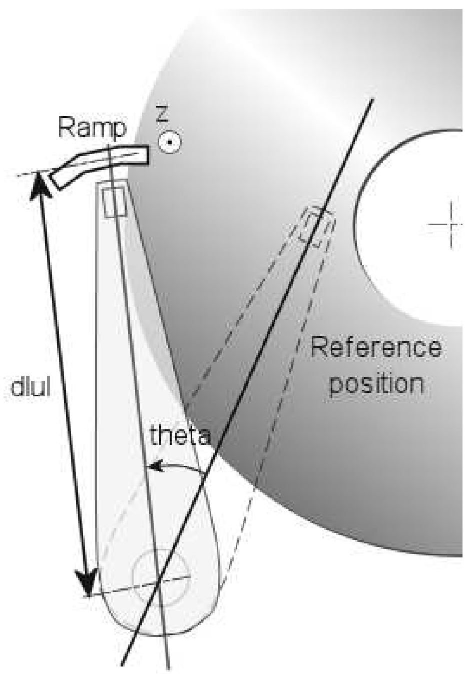

Figure 4: The ramp coordinates

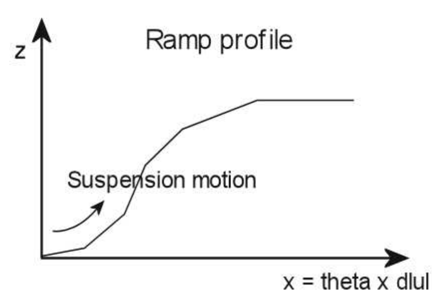

Figure 5: Sample ramp profile

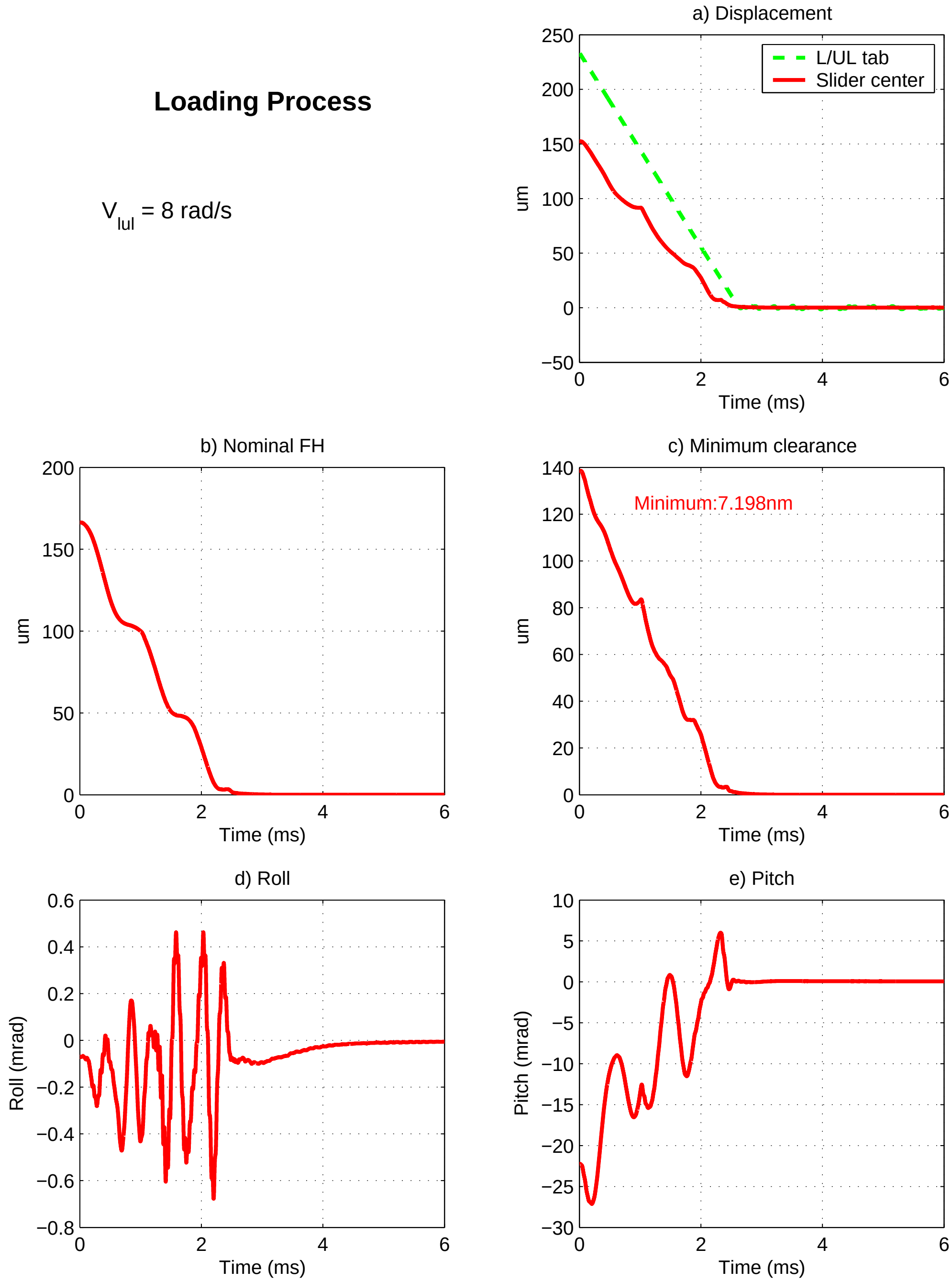

Figure 6: Slider attitude for example 1 plotted using the *displaceLUL* command

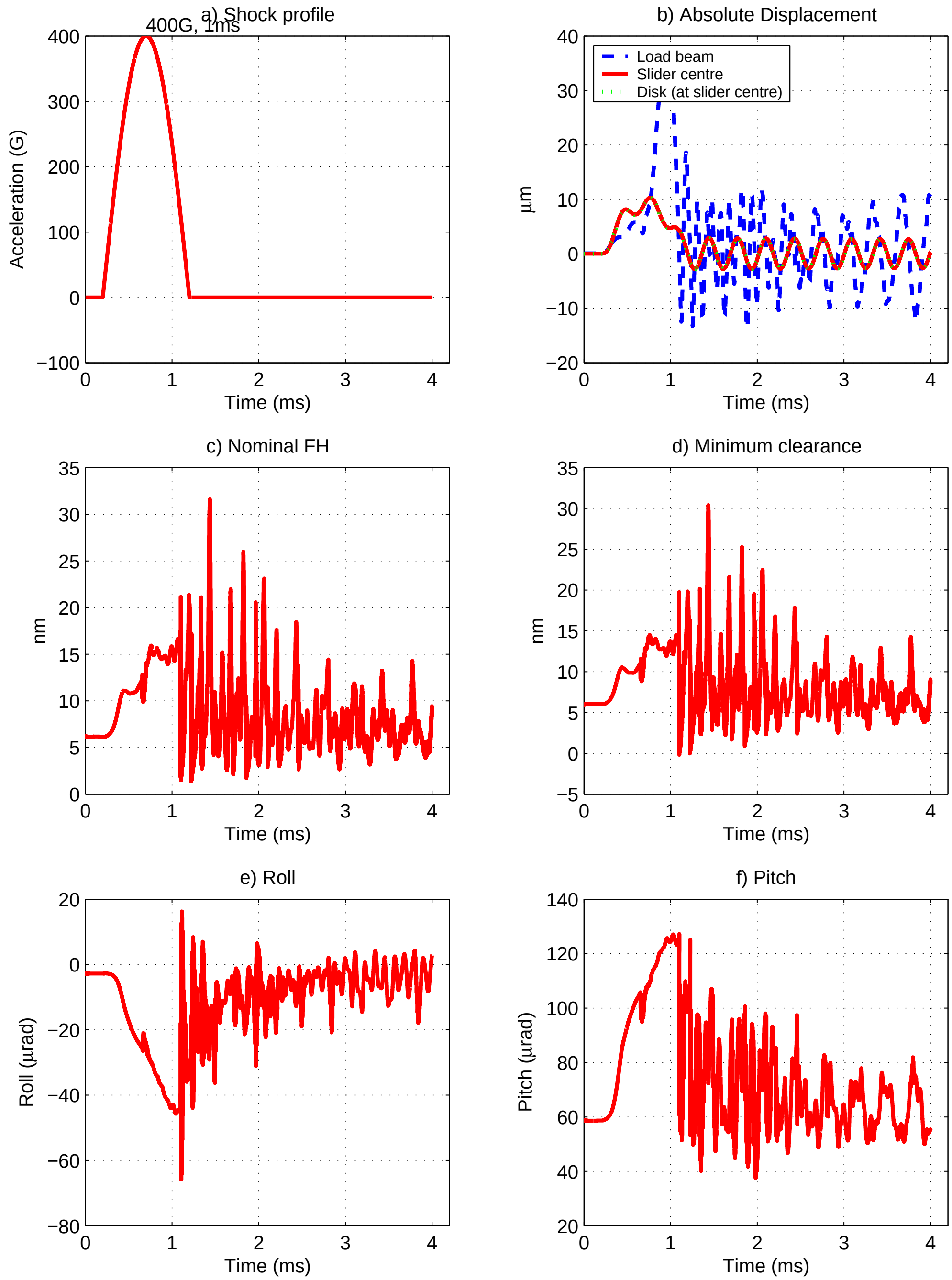

Figure 7: Slider attitude for example 3 plotted using the *displaceSHOCK* command

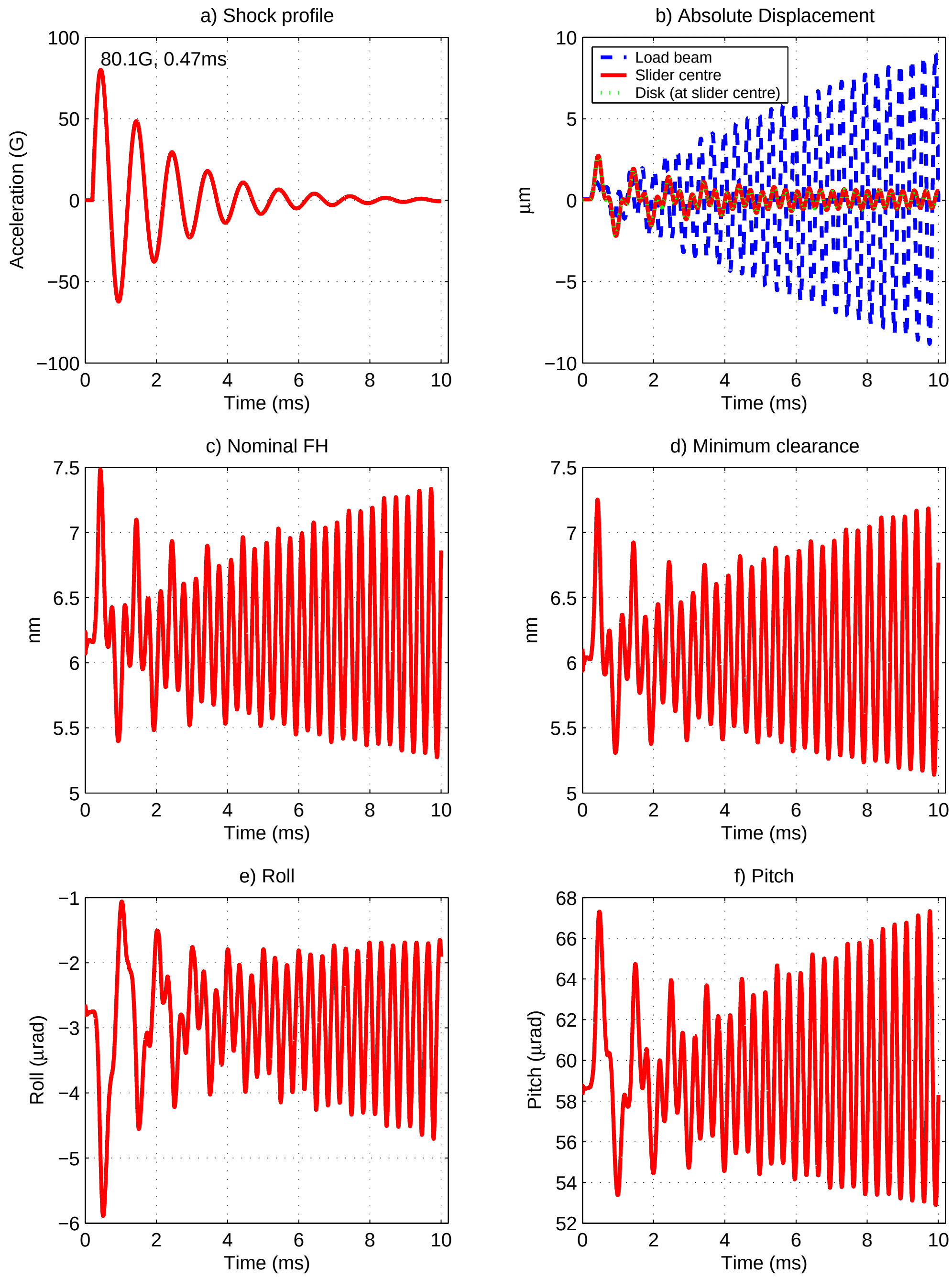

Figure 8: Slider attitude for example 4 plotted using the *displaceSHOCK* command

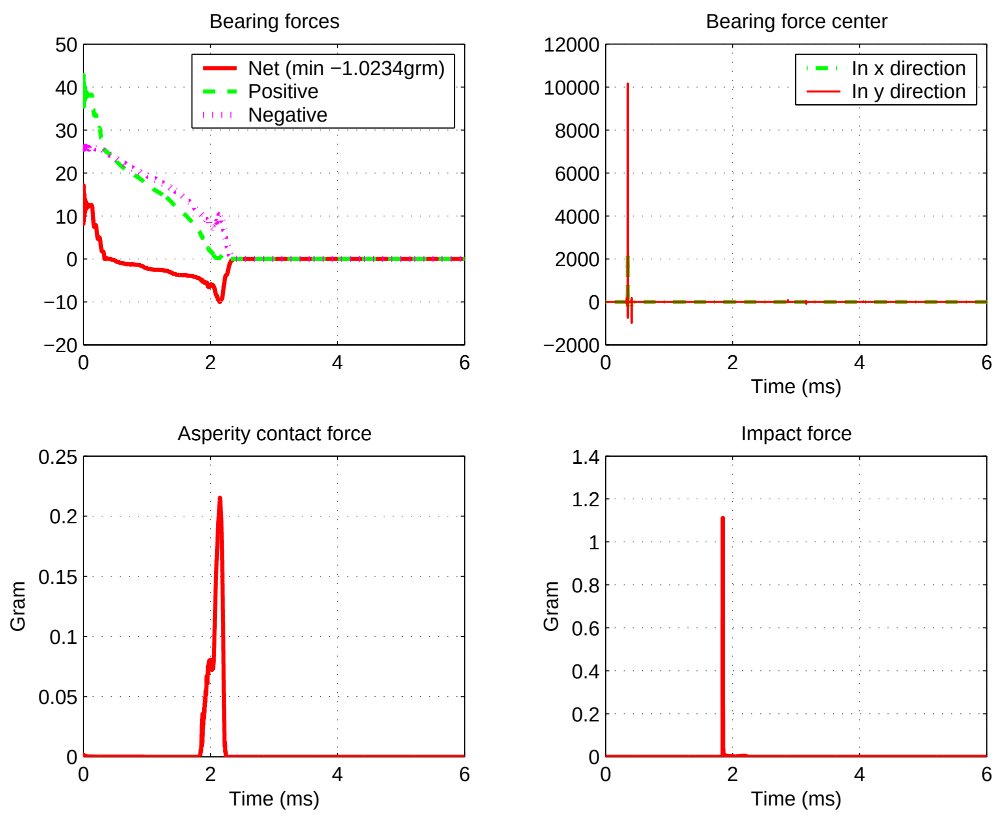

Figure 9: Air bearing and contact forces for example 2 plotted using the *force* command

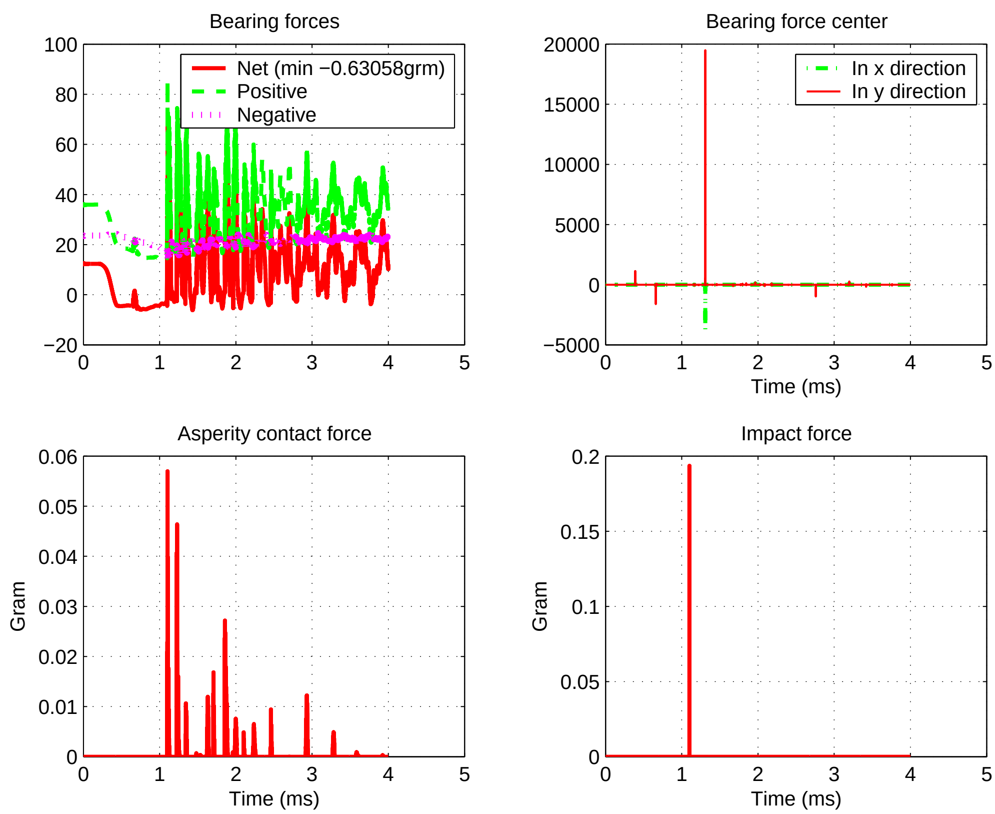

Figure 10: Air bearing and contact forces for example 3 plotted using the *force* command

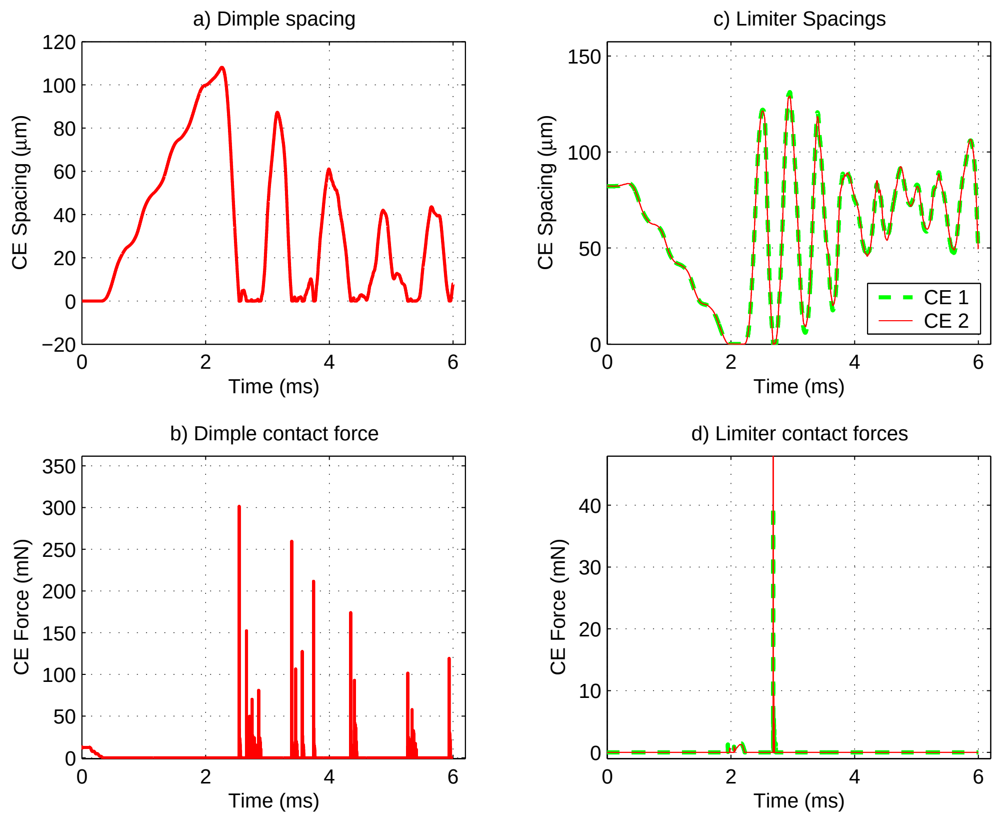

Figure 11: Contact element data for example 2 plotted using the *cestat* command

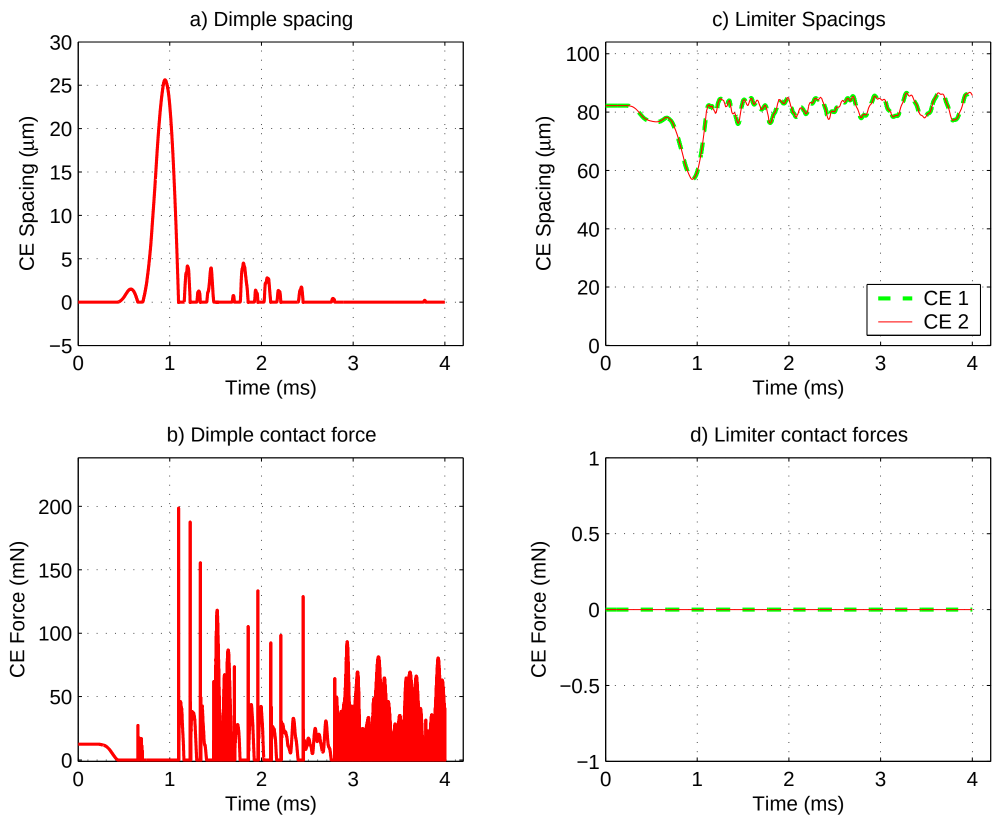

Figure 12: Contact element data for example 3 plotted using the *cestat* command

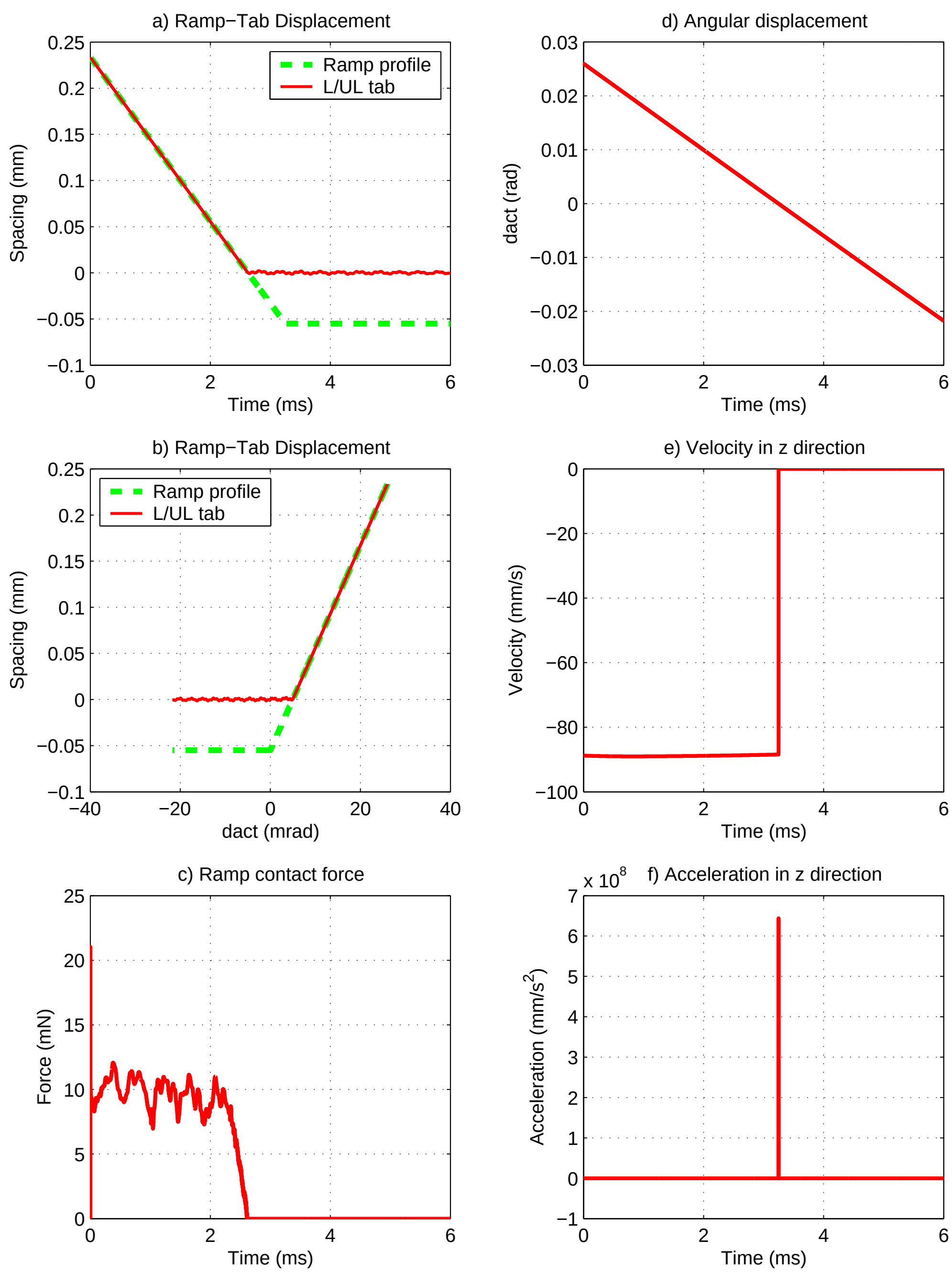

Figure 13: L/UL tab behavior for example 1 plotted using the *lulbehav* command

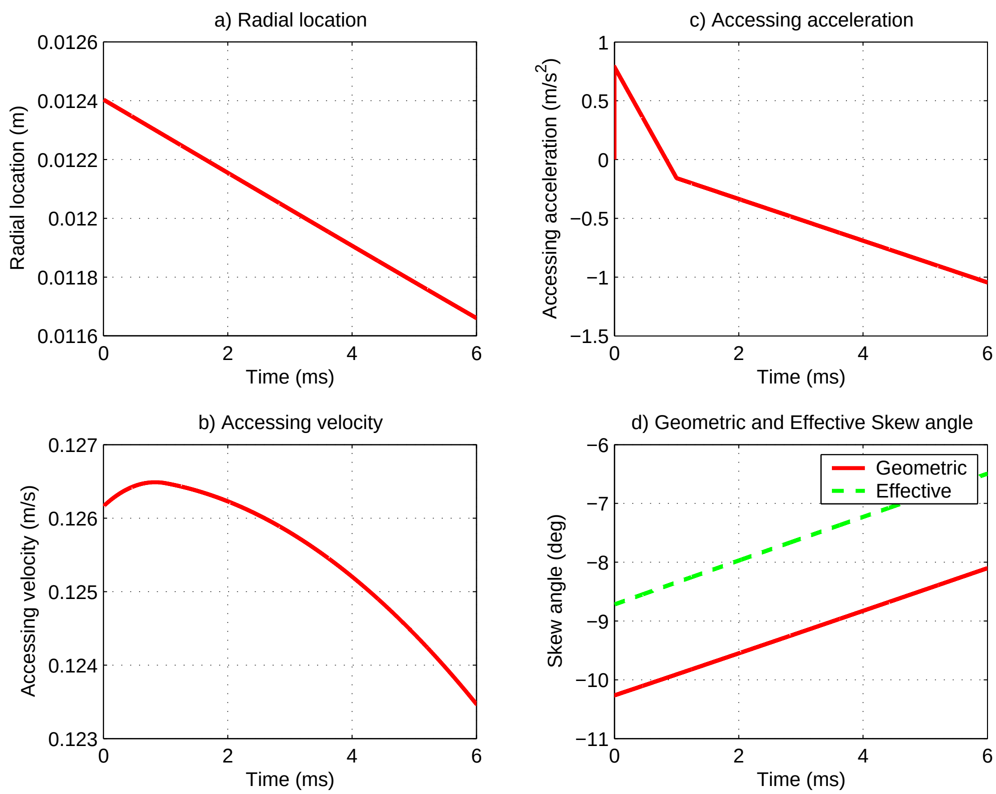

Figure 14: Actuator motion for example 1 plotted using the *actmot* command