# Tippe Top Simulation by LS-DYNA®

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## Abstract

*The tippe top is a toy consisting of a section of sphere and a short rod. When tippe top, whose rod is at top, is rotating, it automatically inverts and the position of center of mass is raised. This toy is simulated by LS-DYNA.*

## Introduction

I bought a set of SAKADATI GOMA (in Japanese Tippe Tops ) at one coin shop. The shapes of all Tops look similar as shown in Fig. 1. Two of them (the largest one and the smallest one) inverted, but middle one did not invert..

I would like to find out what condition is needed for inverting Tops and whether LS-DYNA can simulate these Tops.

Fig. 1

## Theory

In 1977, Chohen[1] published the pioneer works of Tippe Tops. He used the sphere which the center of gravity is not coincide with the center of geometry. He pointed out that the friction force at the point P and the gravity force generate moments which inverts the sphere. The center of gravity move to higher position and becomes stable.

Sakai[2] found the following condition for inverting Tippe Tops:

$$1-a/R < A/C < 1+a/R,$$

where a is the distance between the center of gravity and the center of geometry, R is the radius of sphere, A and C are the mass inertia of moment around the x and the z axis, respectively. Because his paper was written in Japanese, this condition was not known in general. Recently, Ueda, Sasaki and Watanabe[3] analyzed this problem more detail related to

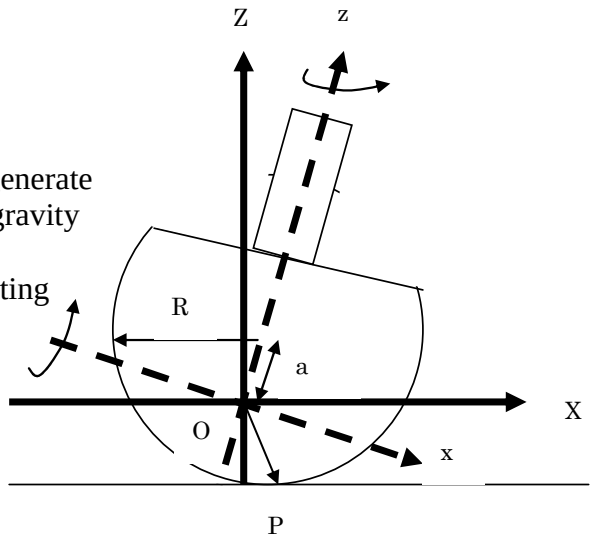



Fig.2

Gyroscopic Balance Condition. They also derived the same condition. According to their paper, three types of Tippe Tops was simulated:

Group I ( A/C < 1-a/R)
Group II (1-a/R < A/C < 1+a/R)
Group III ( 1+a/R < A/C )

## Model

The FEM model of Tippe Tops is created by LS-PrePost®. To decease the computation time, the model is created with shell elements. Note the cylindrical ring indicated by the arrow in Fig.3 which is used to adjust the offset of the center of gravity.

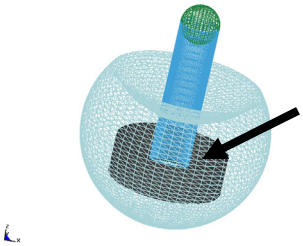


Fig. 3

The size of sphere is R=25mm. All parts are rigid bodies, and floor is also rigid body. The contact is defined as follows:

```
                                                    *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_ID
        $#                                  title
       cid                                                                                  
         1                                                                                  
$#     ssi       msid      sstyp      mstyp     sboxid     mboxid        spr        mpr
         5        100          3          3                                                
        $#                                                                                  
        fs         fd         dc         vc        vdc    penchk         bt         dt
  0.300000   0.300000      0.000      0.000   20.00000         0      0.000   1.0E+20
        $#                                                                                  
       sfs        sfm        sst        mst       sfst       sfmt        fsf        vsf
  0.100000   0.100000      0.000      0.000   1.000000   1.000000   1.000000   1.000000
        $#                                                                                  
      soft     sofscl     lcidab     maxpar      sbopt      depth      bsort     frcfrq
         2      0.000          0      0.000   3.000000          5                        
```

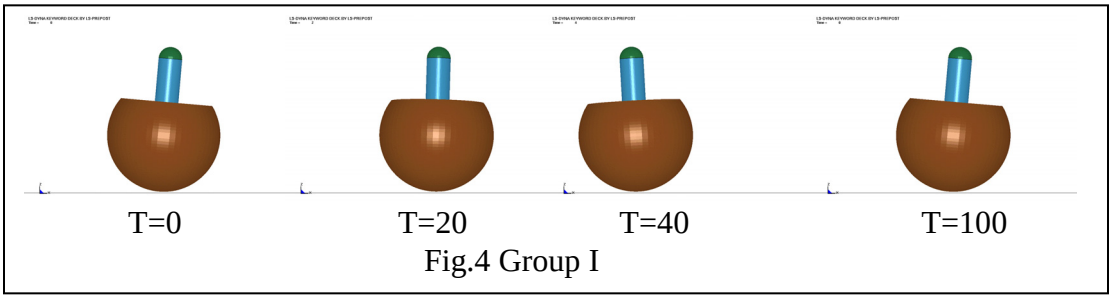
The initial rotational velocity is 300 rad/sec around the Z axis.

Initially, Tippe Tops declines 5 degree around the Z axis. Without this perturbation, the inversion of Tippe Tops does not occur for at least 10sec simulation.

## Simulation Results

A. Group I ( A/C < 1-a/R )

A=0.04271, C=0.04751 and a=1.8
A/C = 0.899 a/R=0.072 1-a/R=0.928



T=0 T=20 T=40 T=100

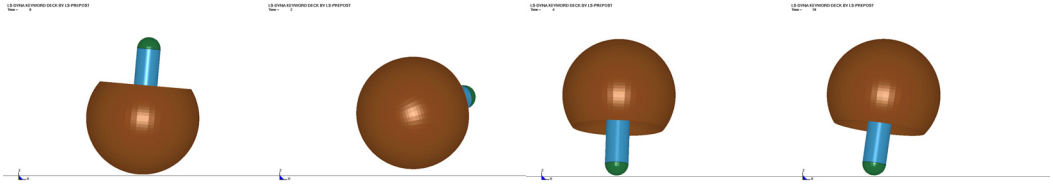
Fig.4 Group I

For Group I, the rod of Tippe Top is oscillating around the initial position and does not invert.

B. Group II ( 1-a/R < A/C < 1+a/R )

A=0.04173, C=0.04751 and a=4.3

A/C = 0.8989 a/R=0.172 1-a/R=0.828 1+a/R=1.172



T=0 T=20 T=40 T=100

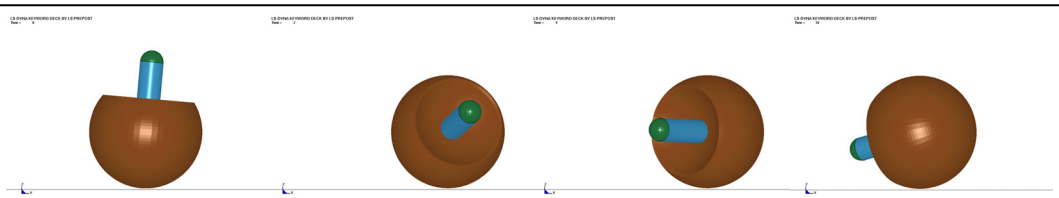
Fig.5 Group II

For Group II, Tippe Top inverts completely.

C.Group III ( A/C > 1+a/R )

A=0.03013, C=0.02801 and a=0.5

A/C = 1.0756 a/R=0.002 1-a/R=0.998 1+a/R=1.002



T=0 T=20 T=40 T=100

Fig.6 Group III

For Group III, initially Tippe Top starts inverting the same as Group II. However, the inversion stops when the rod is in a horizontal position.

## Discussion

The simulation of LS-DYNA confirms the prediction of the theory. The theory assumes that contact occurs at point, but in the simulation the contact occurs in an area. The effect of the difference of the contact has to be checked in more detail.

### References

1)R.J.Cohen, “The Tippe Top Revisited”, Am. J. Phys. 45, 12-17(1977)
2)T.Sakai, “Sakadati Goma( in Japanese, Tippe Tops)”, Suri Kagaku( in Japanese, Mathematical Science) 211,30-36(1981) ( in Japanese )
3)T. Ueda, K. Sasaki and S. Watanabe, “Motion of the Tippe Top Gyroscopic Balance Condition and Stability”, SIAM Journal on Applied Dynamical Systems, 4, 1159-1194(2005)