# Rotating the flying disc in a stereo 3D simulation

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## Abstract

Rigid body motion is part of mechanics that students find hard to understand. It is due to the inability to exhaustively demonstrate such a motion in laboratories. For example, throwing a disc happens fast and the motion cannot be properly observed. Also it is not possible to show vectors describing the rotational motion while the body is moving. These limitations considerably hamper the comprehension of the studied phenomena by students. The current article tries to demonstrate the use of free online stereoscopic 3D simulations as a virtual laboratory. The well known recreation game of throwing a flying disc hides important physical insights. The motion of the flying disc is simulated and the rotation process is analyzed qualitatively. The learning process using the simulation is followed and the student's benefits of utilizing the simulation are disclosed. The used stereo 3D simulation of rigid body rotation can be observed free online at http://ialms.net/sim.

## Resumen

El movimiento de cuerpo rígido es parte de la mecánica que los estudiantes encuentran difícil de entender. Esto se debe a la incapacidad de demostrar de forma exhaustiva dicho movimiento en los laboratorios. Por ejemplo, lanzar un disco pasa rápido y el movimiento no puede ser observado correctamente. Además, no es posible mostrar los vectores que describen el movimiento de rotación mientras que el cuerpo se mueve. Estas limitaciones dificultan considerablemente la comprensión de los fenómenos estudiados por los estudiantes. El presente artículo trata de demostrar el uso de simulaciones gratuitas en 3D estereoscópico en línea como un laboratorio virtual. El juego recreativo conocido de un disco volador esconde importantes conocimientos físicos. El movimiento del disco de vuelo se simula y el proceso de rotación se analiza cualitativamente. El proceso de aprendizaje mediante la simulación es seguido y los beneficios de los estudiantes de la utilización de la simulación se dan a conocer. La simulación estéreo 3D de la rotación del cuerpo rígido utilizada puede observarse gratis en línea en http://ialms.net/sim.

## I. INTRODUCTION

The current paper aims at demonstrating how students could better understand certain physical principles of rigid body motion with the use of free stereoscopic online 3D simulations. A case of a flying disc is discussed.

3D-visualizations in most branches of physics are crucial when considerable level of understanding by students is pursued [1]. Teaching of rigid body motion proves to be a hard task for a number of reasons. The motion of all rigid bodies can be idealized and formalized into two separate kinds of motion. These are linear and rotational motions and they are superimposed while the rigid body is moving in space. In the linear motion the rigid body can be approximated to a particle coinciding with its center of mass. The rotational motion is rather more complex in nature and needs special aids when teaching it to students.

The detailed formalization of rigid body motion is beyond the current article scope and quantitative measure of the rotational motion will not be discussed. A qualitative view of principal ideas shall be presented and visualized by means of online and free stereoscopic 3D simulation of the rotational process performed on a personal computer [2].

Most people are well acquainted with the game of throwing a disc. Nevertheless, for those who do not know, the game consists of throwing a flying disc-shaped glider with diameter in the range of 8-12 inches (20-30 centimeters) made from plastic or light wood. The profile of the disc cross section is similar to an airplane wing, thus creating aerodynamic lift and flying when thrown horizontally from one person to the other. But as the disc is unstable in flight it should be rotated when thrown. This rotation stabilizes the disc and will be the subject of the current paper.

We shall try demonstrating the rotation of the flying disc and explain why and how this rotation stabilizes the disc and how it does not allow the disc turn over while in flight. Furthermore, if we throw the disc with a sway and observe its flight we see that, in practice, the disc tends to stabilize and the initial sway lessens after one or two seconds in the air.
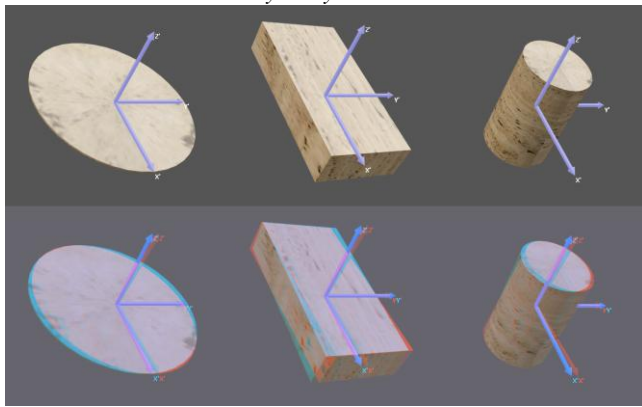
**FIGURE 1.** Principal axes of inertia of three different bodies: disc, rectangular parallelepiped and cylinder. Bodies are shown in normal view mode (above) and stereoscopic anaglyph view mode (below). For the latter view use stereoscopic anaglyph red-cyan glasses ⬛🟦.

## II. PRINCIPAL AXES OF INERTIA

Every rigid body has three principal axes of inertia, which are orthogonal to each other [3]. On Fig. 1 are shown three differently shaped homogenous rigid bodies with their body reference frames (X', Y', Z' vectors) oriented along the principal axes of inertia. The major principal axis of inertia is the one with the greatest inertia capabilities. That is under given constant rotation velocity (angular velocity) the body summons the greatest kinetic energy when rotated about the major principal axis of inertia. Obviously the body should have minor and intermediate principal axes too. The minor principal axis is the one with lowest inertia and the principal axis with medium inertia is the intermediate principal axis.

If a rigid body is initially rotated about the major or the minor principal axis and then is let free it will continue to rotate about the starting axis and will not sway, *i.e.* the rotation will not deviate from this initial axis. On the contrary, if the rigid body is rotated about an axis that is not a major or a minor principal axis of inertia and then is let alone, it will start to sway – the axis of rotation will continuously shift in space in relation to the rigid body. The latter process is called free precession [4].

When a homogenous rigid body is axially symmetric, one of its principal axes goes along the axis of symmetry, while the other two may be freely chosen in the plane orthogonal to the axis of symmetry as far as they are orthogonal to each other [4]. The disc and the cylinder are such rigid bodies (Fig. 1). Rigid bodies with axial symmetry are also called symmetric tops. The free precession of symmetric tops has much simpler pattern than the free precession of the general rigid body (Fig. 2) although they all share the same nature. Observing the trajectory of the disc Z' vector one can see that it is a circle, while the brick Z' axis exhibits a complex spherical cycloid motion (Fig. 2).
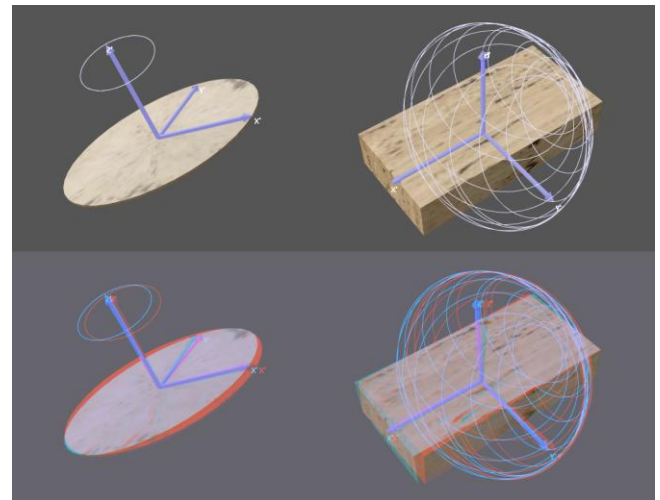


**FIGURE 2.** Free precession of a disc and a brick (rectangular parallelepiped). Shown in normal view mode (above) and stereoscopic view mode (below). For the latter view use stereoscopic anaglyph red-cyan glasses ⬛🟦.

Is there anything special about the major principal axis? Yes, there is. When a body is rotated about the major principal axis it tends to stabilize its rotation and minimize free precession under air drag (external friction). In the case with the flying disc, free precession is undesirable because it will keep altering the disc angle towards the direction of flight. The consequence will be a poor airflow over the disc's surface and even a stall may be caused, making the disc fall shortly after it has been thrown. Fortunately, the flying disc is rotated about its major principal axis (Z' axis on Fig. 2) and air drag will stabilize it. The simulation run with air drag (external friction) is shown on Fig. 3.
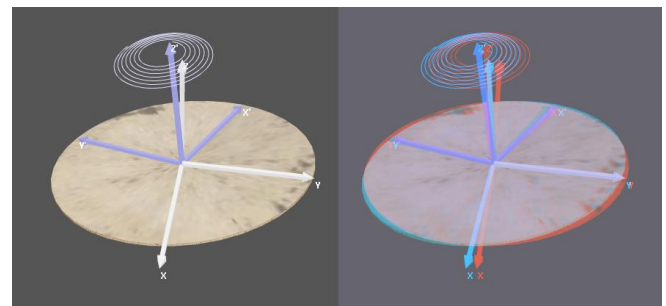


**FIGURE 3.** The influence of the external friction (air drag) on the flying disc free precession. Shown in normal view on the left and stereo view on the right. For the latter view use stereoscopic anaglyph red-cyan glasses ⬛🟦.

It should be also mentioned that if we rotate a symmetric top (*e.g.* a cylinder) around its minor principal axis the air drag will eventually destabilize it – a process called awakening of a sleeping top [2]. The simulation on Fig. 3 shows the process of stabilization of the rotating disc around its major principal axis. The disc is rotated initially about an axis close

to the major one thus exhibiting free precession. Due to air drag (external friction switched on in the simulation) the trajectory of the Z' axis is a spiral, *i.e.* it is a circle with diminishing radius in time. The smaller the circle of the free precession becomes, the more stable the rotation is (Fig. 3).
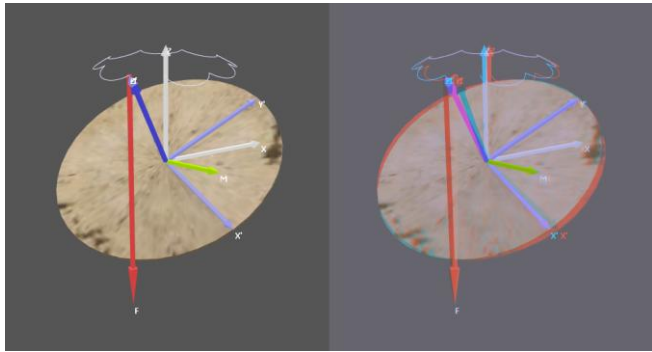


**FIGURE 4.** The influence of the gyroscopic effect on the flying disc. Precession and nutation are caused, but the disc does not flip over. Shown in normal view on the left and stereo view on the right. For the latter view use stereoscopic anaglyph red-cyan glasses.

While the disc's free precession is minimized due to its rotation and drag, there is one further positive effect the rotation causes on the disc's flight. While the disc is flying the air lift is unequally spread over its surface causing a torque that is trying to tilt the disc from its horizontal orientation. The rotation of the disc creates gyroscopic effect and thus the moment of force (torque), instead of tilting the disc, excites a non-free precession, which keeps the disc almost horizontal. On Fig. 4 the non-free precession of the disc caused by the tilting torque is presented. The trajectory of the Z' axis shows the precession and nutation effects [4]. The disc never turns over and keeps its almost horizontal orientation. The force creating the torque is shown with a red vector while its force arm is along the Z' axis. The torque itself is presented with the green vector.

## III. DESCRIPTION OF THE SIMULATION CAPABILITIES AND INTERFACE

The simulation realizes rigid body motion under different conditions. The simplest case is observed when no external forces are acting. The motion is called free rigid body motion until external friction is switched on caused in the real case by air drag.

To start the simulation the student should click on the 'Start' button. Click on the 'Pause' button to pause the simulation. In 'Pause' mode the user may still change the viewpoint of the camera and toggle the display of vectors and other elements. The chosen rigid body is visualized in 3D graphics with textures and light shades to enhance the pleasure of perception. All vectors are also presented in 3D

view as arrows with different colors. The center of mass of the rigid body is at the origin of the space reference frame, whose vector axes can be seen by selecting the 'Show coordinate axes' checkbox (see Fig. 5).
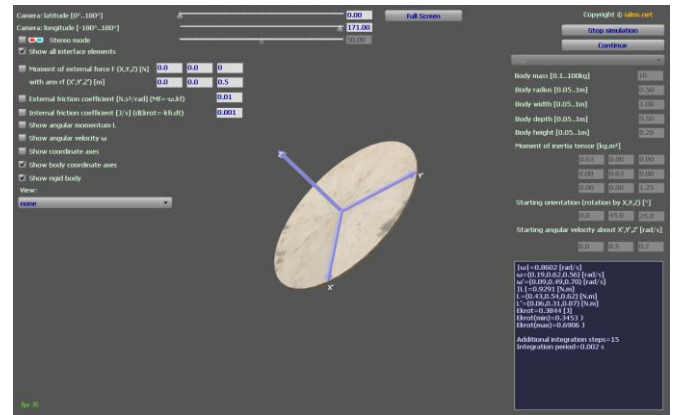


**FIGURE 5.** Simulation interface shown in normal view mode.

The space reference frame basis is presented with white colored vector arrows. The body reference frame's origin is at the center of mass as well. To view the body frame axes check the checkbox 'Show body coordinate axes' (vector arrows in blue-cyan color). The student may also display the angular velocity vector (orange color) showing the momentary axis of rotation. For more complex studying, the angular momentum vector (magenta color) can be visualized by checking the corresponding checkbox (Figure 5). In the data panel (lower-right of the interface), values of the presented vectors are printed continuously along with other scalar values inherent to the simulated process such as the kinetic energy of rotation. At any moment the viewer may hide the excessive controls from the interface by unchecking the 'Show all interface elements' checkbox. To control the camera viewpoint, the user may manipulate the sliders found at the top of the interface. They control camera latitude and longitude. Before running the simulation, the student may enter values for the initial body orientation through three consecutive rotations along the three axes in the space reference frame ('Starting orientation' fields). Also before start, the initial angular velocity may be set using the 'Starting angular velocity' fields. Note that the latter values are specified in respect to the body reference frame (prime axes in blue-cyan color shown on Fig. 5). The viewer may also choose from a number of body types using the drop-down select box found in the upper-right corner of the interface. Then, setting the body mass and dimensions in the corresponding fields below completely defines the rigid body characteristics. Note that the rigid body is homogenous.

After the simulation is started, the student may switch between different viewing modes from the 'View' drop-down select box in the lower-left corner of the interface. There are a number of view modes, from which only 'Z'-axis trajectory' will be used. Choosing this option will draw the trajectory of the Z'-axis of the body reference frame. This

axis happens to be the major principal axis of inertia for the disc body, which shall be examined. The rigid body itself may also be hidden from view by unchecking the checkbox 'Show rigid body'. This allows better view of the body axes which coincide with the principal axes of inertia.

At any moment, the viewer may switch the simulation into 3D-stereoscopic view mode using the checkbox 'Stereo mode' checkbox. In stereo mode students may observe the process using 3D-stereoscopic red-cyan anaglyph glasses [5].

## IV. CONCLUSION

The powerful visualization of stereo 3D interactive simulations is a fruitful approach to teaching physics on a personal computer, either at school level or at the universities. Stereo 3D simulations disclose the hardly to understand details of physics phenomena to students, expanding the boundary of e-learning physics. The illustrated technologies of the stereo 3D vision are all realized as free online learning tool and tend to run on a wide range of personal computers and operating systems.

## REFERENCES

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