AE2220, Report 3

Dynamics of a Triple Twist Bars Dismount

(Continued from Previous Report entitled: "Dynamics of an Underswing Dismount from a Bar" and "Dynamics of a Flyaway Tucked Dismount from a Bar")

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Introduction

The final report in our continued analysis of the dynamics of gymnastics is about the addition of two or more rotations. We have chosen a gymnastics element that involves the gymnast rotating about more than one axis. As before, this analysis will involve a break-down of the element and what defines it, a demonstration of the type of motion involved, a simulation modeling the motion, and an explanation of the theory driving the simulation.

Description of Gymnastics Routine

The element we have chosen to analyze is the Triple Twist Bars Dismount, which is as it sounds, are three twists performed while dismounting from a bar. The gymnast gains momentum by rotating forwards about the bar, then she lets go just as she passes beneath the bar in order to get the maximum amount of airtime. Right as she lets go, she makes sure to keep her body completely straight and brings her arms in to rotate about her vertical axis (the axis that runs from head to toe) as fast as possible. This is what is called the “twist” in the motion and moves that involve this motion include “twist” in their name.

The Twist occurs at the same time another rotation occurs, which is about the axis defined by the bar itself. The gymnast, while twisting, rotates fully around the bar axis to come to her feet when she reaches the mat. A diagram of the Triple Twist Bars Dismount can be seen below:

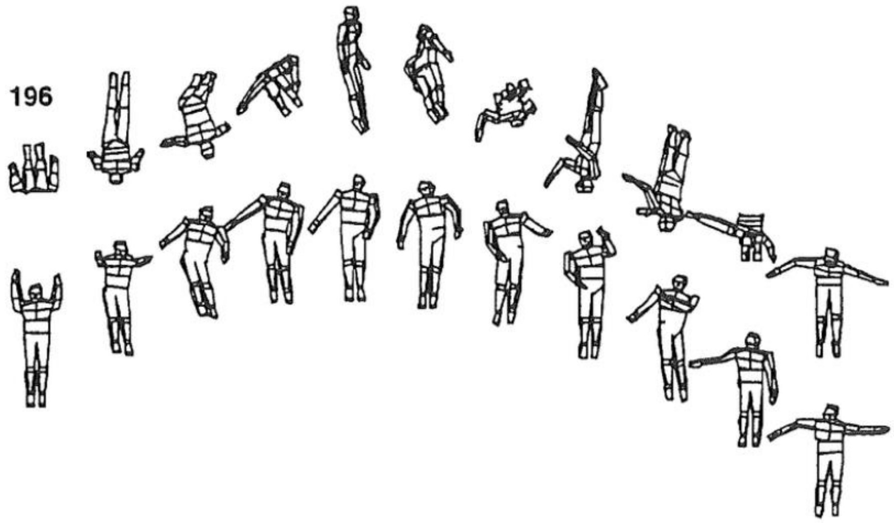


Figure 1. Triple Twist Bars Dismount diagram [11]

As in other gymnastics elements, it is vital to reach the mat and not stumble, touch the mat with one's hands, or jump again. It is also very important with the twist maneuver that a gymnast remain rigidly in the vertical position without bending her knees, hips, or neck.

With the addition of the twist, this element is difficult to achieve and can be seen in professional competitions, which makes it unlike the other elements we have analyzed thus far.

Theory and Analysis

As mentioned, the gymnastics maneuver of the Triple Twist Dismount builds off from the first maneuver, underswing dismount, from the first report but it is with a twist. Since this maneuver needs to be analyzed as a 3D rigid body, assumptions are made to simplify the analysis. The following three concepts are applied for this maneuver: angular velocity, angular momentum, and moment of inertia. Like the previous maneuvers, the inertial reference frame is located at the origin, which is centered at the ground level of the start of the bar. In addition, the time frame of this maneuver is the same from the start of the dismount until the landing on the ground. Throughout the maneuver, the angular momentum is said to be conserved. Unlike the flyaway tuck, the triple twist maneuver does involve the change in rigid body shape, so the shape is constant throughout. This time. the gymnast is modeled as a cuboid shape, so the moment of inertia about the center of mass can be found using the following equations:

$$I_{xx} = \frac{m}{12}(b^2 + c^2) \tag{1}$$
$$I_{yy} = \frac{m}{12}(c^2 + a^2) \tag{2}$$
$$I_{zz} = \frac{m}{12}(a^2 + b^2) \tag{3}$$

Where a, b, and c are the lengths in the x, y, and z-axis respectively and m is the mass of the gymnast.

The angular momentum can be found using the moment of inertia from Equations 1 through 3 into the following equation:

$$\begin{Bmatrix} H_x^C \\ H_y^C \\ H_z^C \end{Bmatrix} = \begin{bmatrix} I_{xx}^C & I_{xy}^C & I_{xz}^C \\ I_{yx}^C & I_{yy}^C & I_{yx}^C \\ I_{zx}^C & I_{zy}^C & I_{zz}^C \end{bmatrix} \begin{Bmatrix} \omega_x \\ \omega_y \\ \omega_z \end{Bmatrix} \tag{4}$$

Where H is the angular momentum, ω is the angular velocity, and I is the moment of inertia.

For this case, $I_{xy}^C = I_{xz}^C = I_{zy}^C = 0$. It is important to note that the angular velocity vector is in the body frame of the gymnast, which needs to be translated to the inertial reference frame. More on this can be found in the Coding and Simulation section.

Demonstration and Experimentation

The final rendition of the experiment involves the past two experiments combined, plus the addition of another rotation that is in another dimension. The experiment performed is a slight modification of the original experiment: an object is thrown in a parabolic arc, but there are two rotations occurring on the object.

The requirements for this demonstration are less than those of the previous experiment, but there is more of a requirement from the process. The only item necessary is a water bottle; however, the ease and visibility of rotation depend on the differentiation of colors on the water bottle. In this circumstance, the water bottle is tossed from the thrower at an odd angle such that it has rotation in both the x- and z-axis. The thrower should also throw the bottle upwards as to create parabolic motion. This ensures that the demonstration is performed correctly.

Figure 2: Wide view of water bottle throw. Notice the bottle in the top left center of the image.

Figure 3: Large cross-like markings on the water bottle.

The image directly above shows the markings on the water bottle (visible as plus signs) as it falls back towards the earth. The resolution of the camera filming the slow-motion fall could be better and could hence show the rotation of the bottle much clearer. In retrospect, using brighter colors and better cameras could have shown a clearer 3D rotation of the water bottle, but the demonstration was clear enough to understand. This demonstration showed the three distinct motions that are modeled and explained in this report: a rotation in the x-axis, a rotation in the z-axis, and the parabolic motion of falling from a higher point.

Coding and Simulation

This code is a continuation of part one of the gymnastics project and as such uses almost all the same code as the first part. This means the code finds the distance the gymnast travels, the max height reached, and the time it takes to do so. The type of flip that is being modeled requires a rotation of about 2 axes. The gymnast does ¾ of a flip while also twisting 3 times. The ¾ flip is the same as part 2, but the twisting is new. This requires a 3D model of the rotation of the gymnast. An iterative method is used with the velocity calculated over a small dt then summed to find the angular position. First, the moment of inertia must be found. The gymnast was assumed to be in the shape of a cuboid with a moment of inertia of:

$$I = \frac{1}{12} m l^2 \begin{bmatrix} 5 & 0 & 0 \\ 0 & 1.7 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

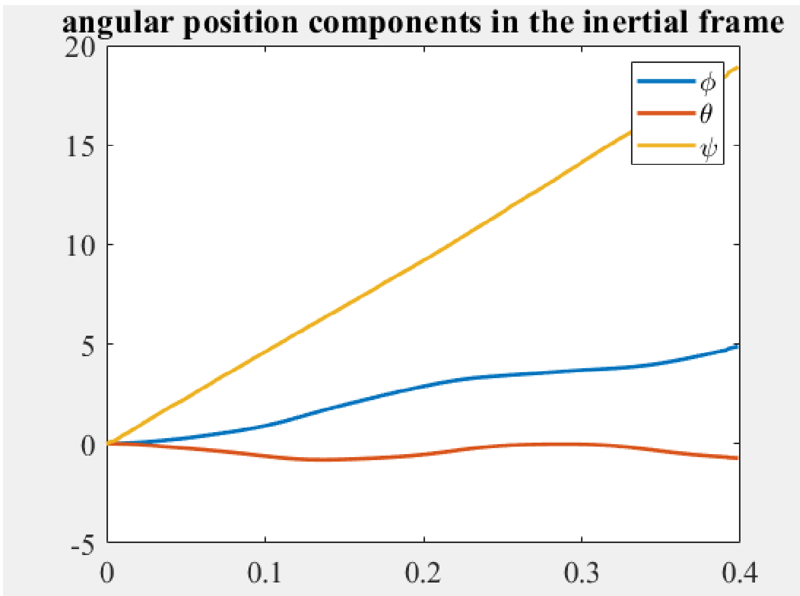
After that is found, the 6 initial conditions which are all 0 except the two initial rotations and the time interval must be inputted into MATLAB’s ODE45 function in order to find all the necessary results. The first 3 equations are:

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & 0 & -\sin\theta \\ 0 & \cos\phi & \cos\theta\sin\phi \\ 0 & -\sin\phi & \cos\theta\cos\phi \end{bmatrix}^{-1} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

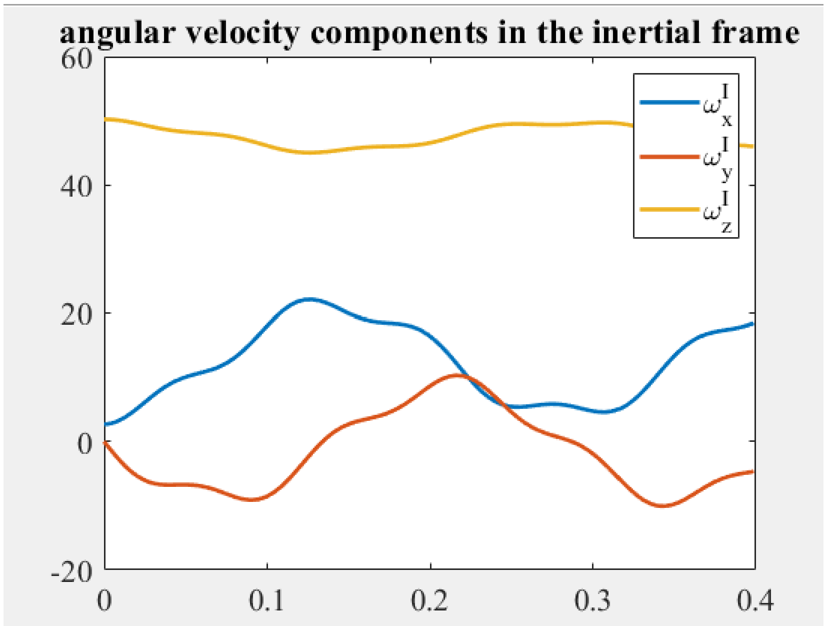
And the second 3 are:

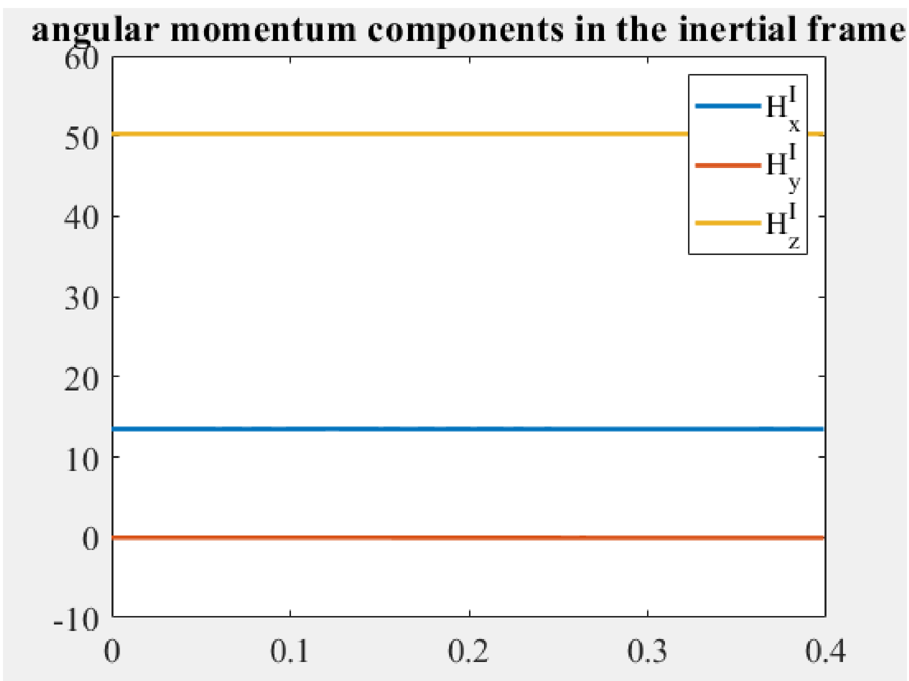
$$\begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = [I]^{-1} \left(\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} x \left(I * \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} \right) \right)$$

Then the terms in the matrix can be converted into the inertial frame and the angular momentum and velocity can be graphed. Note that the angular momentum in the inertial frame must be constant. Once the angular velocity is found, the angular position can be found by integrating it using the dt values that the ode function finds. It is found that an initial angular velocity of 2.7 rad/s is needed in the x-axis for the front flip and 50.3 rad/s is needed in the z-axis to do the twist. With these initial conditions, the gymnast does the required 3 twists and ¾ of a flip.

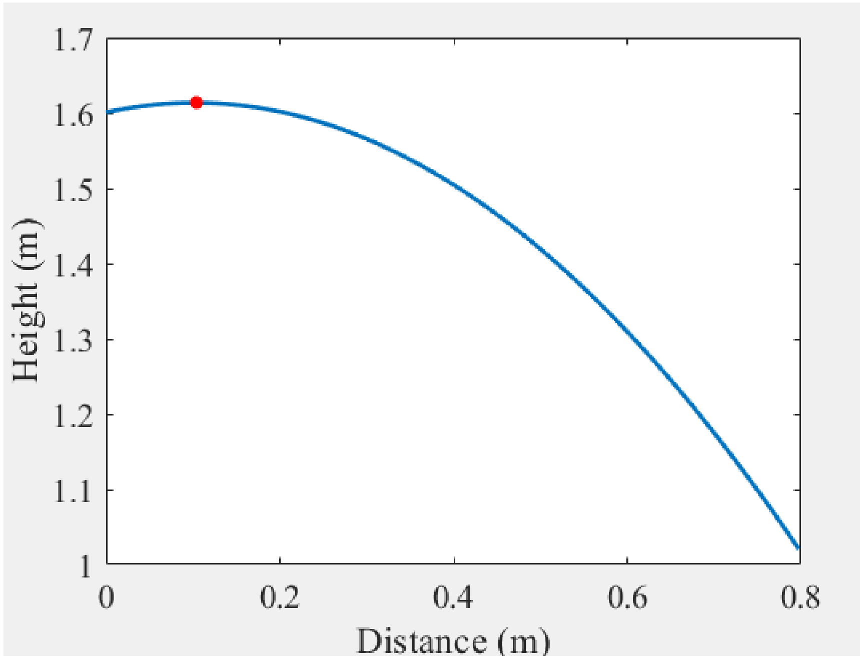


The gymnast has very little change in the rate of twist, but the forward flip seems to vary a little.





The angular momentum in the inertial frame remains constant.



Conclusion and Lessons Learned

Through further research into the 3D dynamics of gymnastics and with the basis created by our previous reports, we have developed a greater understanding of the comprehensive effects of rotations in the motions of a Triple Twist Bars Dismount. Through the process of updating our demonstrations and simulations from a 2D model, we found that adding an additional axis in gymnastics created the additional consideration of angular velocity and position within that axis. Additional research and attention to detail were required as we made the leap from a 2D model to a 3D model. We built off our initial paper and continued to expand into the realm of modeling rigid bodies in 3D space. While our new approach with rigid bodies is more accurate, it still contains a few inaccuracies – it does not account for a lot of the real-world external forces such as drag or friction similarly to our previous models. Even with these inaccuracies and modeling and demonstration troubles, this report provides a basis for further modeling that could include more of the factors governing the real-world demonstration of gymnastics. The creation of this latest model was heavily aided by our previous reports. From this project, we have learned about the cumulative accumulation of research and how to innovate based on previous bases from previous reports. From this report, we have learned about the effects of multiple rotations vs a single rotation and the differences between modeling rigid bodies in a 3D space vs modeling rigid bodies in a 2D space. As this project continues, we hope to include more of the external factors and increase the complexity of our model to create a more accurate model of gymnastics and to further expand this modeling technique to aerodynamics.

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