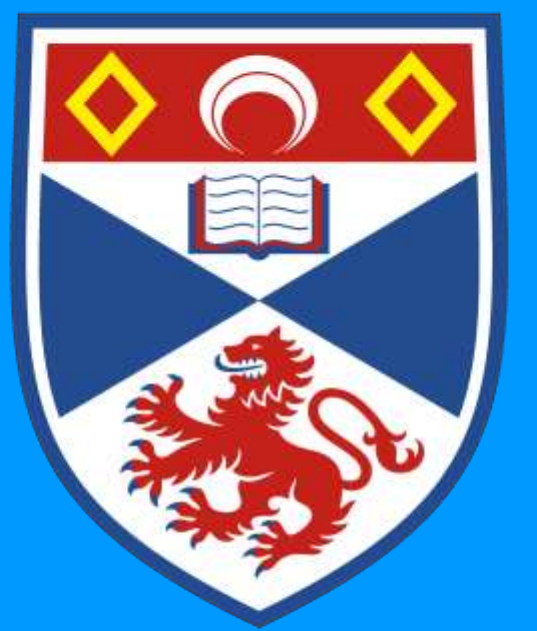


On the Impact of Dzhanibekov's Effect on Earth Dynamics: Scaled Experiments with Free-falling Rotating Bodies

By Mateo Guzmán Subiría

Supervised by Dr Irena Vorgul

School of Physics and Astronomy, University of St Andrews, UK



University of St Andrews

Project Overview

The project explores Dzhanibekov's effect and the possibility of it influencing Earth's dynamics. We suggest a more general theory than the conventional Intermediate Axis Theorem (IAT). We built an experimental set up and used it to explore the effect on rotating bodies in free fall, with particular interest in those partially filled with liquid which model the Earth.

Quasi-linear Theory

Our quasi-linear theory allows Dzhanibekov's effect to occur along other axes given an adequate combination of parameters. The IAT is only a particular case.

$$\ddot{\omega}_3 + D\omega_3 = \frac{\dot{M}_3}{C} - \frac{(B-A)(M_1B\omega_2 + M_2A\omega_1)}{ABC}$$

where

$$D = -\frac{B-A}{ABC} [B(C-B)\omega_2^2 - A(A-C)\omega_1^2]$$

A, B, C are the moments of inertia, $\omega_{1,2,3}$ are the angular velocities and $M_{1,2,3}$ effective torques corresponding to axes x, y, z . We assume a rotation about axis z .

If $D > 0$, ω_3 changes periodically between positive and negative values, which would describe flipping in rotation. The theory predicts flipping for a rigid Earth with the parameters from Ref. 3.

Aims/Method

We aimed to perform observations on rigid and liquid-filled objects with exaggerated asymmetries varying the angular speed and rotation axis at launch. The asymmetries were exaggerated because if we scaled the dimensions of the Earth to the experiment the flipping time would be infinitely long. We intended to extrapolate our results from these exaggerated asymmetries back to the parameters of the Earth.

Set Up

One device spins and then releases a test object. The other device guides a falling camera pointing at the object in free fall. The falling speed of the camera can be controlled to match that of the object.



Figure 2: The set up used to observe spinning falling objects.

Acknowledgements

I thank my supervisor, Dr Irena Vorgul, Lord Laidlaw, and the Laidlaw Foundation for giving me the opportunity to work on this project. Appreciation is given to my fellow Laidlaw scholars, my friends, and my girlfriend Natalia for supporting me.

Dzhanibekov's Effect

The effect describes the sudden flip experienced by asymmetric rotating bodies. According to the IAT, flipping only occurs when the object spins about near its intermediate principal axis (Ref. 1).

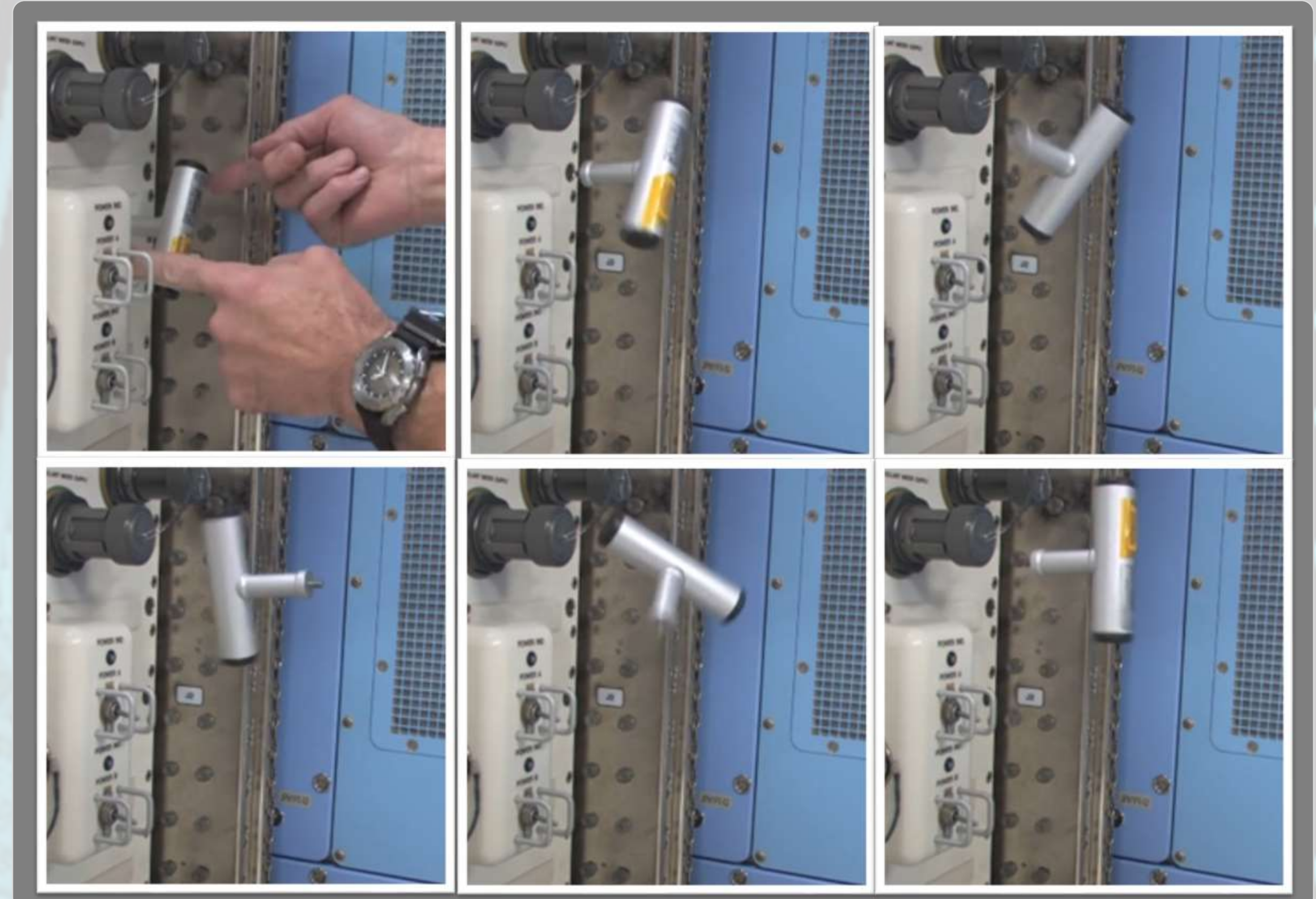


Figure 1: Dzhanibekov's effect on a T-handle in microgravity. Clips from the original video are chronologically ordered left to right and top to bottom. From YouTube, 2009 (Ref. 2).



Results and Conclusions

A code was developed to calculate the principal moments of inertia of the bodies we experimented with. A number of complications resulted in limited data collection. We observed 4 objects perform partial or full flipping (scan the QR codes to watch the recordings) with periods falling within ranges given by quasi-linear theory calculations. We calculate a lower constrain for the flipping period for a rigid Earth at ~110 years. A body partially filled with liquid can flip too but, depending on the parameters of the liquid and other parts of the body, this flip could be either complete or incomplete. The liquid inside the body would be affected, which in the case of the Earth would result in some changes to the global magnetic field. The results are pre-requisites for further research and could lead to a new direction of research into the Earth dynamics, the terrestrial magnetic field, and climate change.

References

- 1) Garelli, L., Storti, M. and Trivisonno, N. The Tennis Racket Theorem, Analysis and Numerical Simulation of the Intermediate Axis Theorem. *Mecánica Computacional*, 2021; (Vol. 28), pp. 1353-1365.
- 2) Plasma Ben. Published 3 of March 2009. Dancing T-handle in zero-g, HD. [Video]. YouTube.com. <https://www.youtube.com/watch?v=1n-HMSCDYtM>
- 3) Chen, W. and Shen, W.B. New estimates of the inertia tensor and rotation of the triaxial nonrigid Earth. *Journal of Geophysical Research*, 2010; B12, (Vol. 115). DOI: 10.1029/2009JB007094

Background image:

Andrews, B. (2019). *When Earth's magnetic field flips, it could take thousands of years*. Astronomy. Accessed September 1st at <https://astronomy.com/news/2019/08/when-earths-magnetic-field-flips-it-could-take-thousands-of-years>