Modelling the Motion of a Knuckleball

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1 Problem

While the physics behind the trajectories of projectiles has been well-studied for centuries, creating realistic models of this motion still remains a difficult task. This is exemplified by the motion of baseball pitches such as the knuckleball—in addition to the well-studied effects due to gravity and drag forces, the seams of the ball can introduce additional effects that are challening to predict. Recent studies have predicted that the erratic motion of the knuckleball can be modeled by a force of the form:

$$C_L(\theta) = a_0 \sin(4\theta - \pi) + a_1 \sum_{i=1}^{n} \Big[\sin(\frac{||\mathbf{s_i} - \mathbf{p}||\pi}{2d} + \pi/2) \cdot \text{sgn}(p^* - s_i^*) \Big], \tag{1}$$

which depends on the angle of attack of the ball θ as well as the forces caused by vortex shedding and the sum of forces produced by the seams. More specifically, $\mathbf{p}$ is the stagnation point and $\mathbf{s_i}$ is the position of the i-th stitch. We'd like to model the type of motion predicted by this equation, and how the sensitivity of this motion to initial conditions.

2 Approach

Integrator methods can be used to compute the motion of a baseball subject to this force. The weight coefficients a_0 and a_1 can be taken from Escalera Santos et al. [2019], and the attack angle should be varied to study the effect on the baseball's motion. The motion of the knuckleball should also be compared to the motion of a "normal" baseball subject to the same initial conditions, but only forces from drag and gravity.

3 Objectives

1. Use the integrator methods discussed in class to model the motion of baseball subject to gravity, quadratic drag, and Magnus effects. Justify your choice of integrator.
2. Use the same integrator method to model the motion of a knuckleball, or a baseball subject to the force $C_L(\theta)$ in Equation 1.
3. For the knuckleball, determine how the motion changes as a function of attack angle by running your code for a range of θ values.
4. Compare the motion of a knuckleball to that of the normal pitch subject to the same intiial conditions.

References

Gerardo J. Escalera Santos, Mario A. Aguirre-López, Orlando Díaz-Hernández, Filiberto Hueyotl-Zahuantitla, Javier Morales-Castillo, and F-Javier Almaguer. On the Aerodynamic Forces on a Baseball, With Applications. *Frontiers in Applied Mathematics and Statistics*, 4:66, January 2019. ISSN 2297-4687. doi: 10.3389/fams.2018.00066. URL https://www.frontiersin.org/article/10.3389/fams.2018.00066/full.