The Perfect Pitch - Baseball Meets Computational Physics

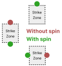
Blake Sanie | Georgia Tech | PHYS 6260, Dr. John H. Wise

Background and Topic

Pitchers apply spin to thrown balls to induce deceiving movement. Can we model this behavior and further analyze the peak of human pitching ability?

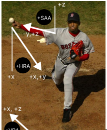
Are the following scenarios possible?

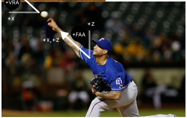
1. "Rise" Ball rises as intersecting strike zone
2. "Dive" Ball crosses entire strike zone vertically
3. "Drift" Ball crosses entire strike zone horizontally



Problem Frame

(Top-down view)





Parameters

- Initial Position (Cartesian)
- Initial Speed
- Horizontal Release Angle (HRA)
- Vertical Release Angle (VRA)
- Forward Arm Angle (FAA)
- Side Arm Angle (SAA)
- Ball Spin (Spherical)

Mechanical Modelling

Acceleration by:

Gravity: $\vec{a}_G = (0, 0, -g)$

Air Resistance (Drag): $\vec{a}_D = \frac{1}{2m} C_D \rho A |\vec{v}|^2 \hat{v}, C_D = .40$

Magnus Effect:

$$\vec{a}_M = \frac{1}{2m} C_M \rho A |\vec{v}|^2 (\hat{\omega} \times \hat{v}), C_M = .39 S^{.31}, S = \frac{2\pi r |\vec{\omega}|}{|\vec{v}|}$$

Accelerating influence of velocity

Direction of lift

Diminishing magnitude for each next RPM

Simulation Methods

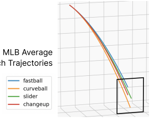
Runge-Kutta, 4th Order (RK4)

$$f(\vec{v}, \vec{\omega}, t) = \vec{a}_G + \vec{a}_D + \vec{a}_M$$

$$\begin{aligned}
k_{1,\vec{v}} &= h * f(\vec{v}, \vec{\omega}, t) \\
k_{2,\vec{v}} &= h * f(\vec{v} + 0.5 * k_{1,\vec{v}}, \vec{\omega}, t + 0.5 * h) \\
k_{3,\vec{v}} &= h * f(\vec{v} + 0.5 * k_{2,\vec{v}}, \vec{\omega}, t + 0.5 * h) \\
k_{4,\vec{v}} &= h * f(\vec{v} + k + 3, \vec{v}, \vec{\omega}, t + h) \\
\vec{v} &= \vec{v} + (k_{1,\vec{v}} + 2 * k_{2,\vec{v}} + 2 * k_{3,\vec{v}} + k_{4,\vec{v}})/6
\end{aligned}$$

$$\begin{aligned}
k_{1,\vec{x}} &= \vec{v} \\
k_{2,\vec{x}} &= \vec{v} + 0.5 * k_{1,\vec{v}} \\
k_{3,\vec{x}} &= \vec{v} + 0.5 * k_{2,\vec{v}} \\
k_{4,\vec{x}} &= \vec{v} + k_{3,\vec{v}} \\
\vec{x} &= \vec{x} + h * (k_{1,\vec{x}} + 2 * k_{2,\vec{x}} + 2 * k_{3,\vec{x}} + k_{4,\vec{x}})/6
\end{aligned}$$

MLB Average Pitch Trajectories



MLB Best Pitch Trajectories (by RPM)

Search Methods

Nested Binary Search

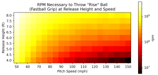
As human exertion parameters (ball speed, spin rate) change, aiming (HRA, VRA, FAA, and SAA) must be simultaneously tuned to achieve the end-simulation target scenario.

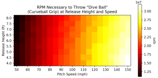
1. Define lower and upper bound human exertion parameters
2. Determine best-case aim
   a. Terminate if target scenario is physically unreachable
   b. Define lower and upper bound aiming parameters
   c. Find necessary aiming parameters with Binary Search
3. If the target scenario is physically reachable but not minimally ("barely") reachable, recurse on the partitioned parameter space where exertion can be safely reduced.

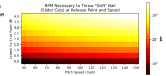
This is necessary, for example, to not only ensure that a "Rise" Ball can occur by a solution set of exertion parameters, but those solutions are themselves the minimum necessary to "barely" rise the ball when intersecting the strike zone.

Final Results and Conclusions

- In the pursuit of recreating a "Rise", "Dive", and "Drift" ball, it is evident that super-human physical ability would be necessary.
- Nonetheless, each density plot reveals the relationship between each inspected exertion parameters themselves and the target scenario.
- "Rise" Ball - As pitch speed increases beyond human-capable levels, the effect of release height becomes increasingly insignificant. Required RPM values are noticeably larger than the other pitches in order to directly overcome gravity's effects.
- "Dive" Ball - Release Height does not play a significant effect in RPM requirement; Pitch speed is the driving factor. Additionally, required RPM increases approximately linearly with pitch speed.
- "Drift" Ball - Releasing the ball further in the -y direction requires a lower spin rate because the Magnus Effect must only reproduce a smaller horizontal release angle difference.







Source code on GitHub