The Perfect Pitch: Baseball Meets Computational Physics

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Abstract

Within the game of baseball, pitchers apply spin to their deliveries to create deceptive movement. Three deliveries regarded as urban legend are the "Rise"-Ball, "Dive"-Ball, and "Drift"-Ball - all scenarios that are claimed to have been seen, but physically questionable. This project determines the minimum feasible spin rate required by pitchers to complete each inspected delivery. Precise simulation models and optimization search procedures are designed to answer such questions. The results presented indicate that spin rates orders of magnitude above the upper-bound of human performance are required to produce such scenarios. To expand, the infeasibility of these deliveries by human pitchers suggests that human perception biases exaggerate the curve effect of spin-defined pitches. Further, this project's modelling methods and approach serve as a foundation for future physical movement feasibility analysis, both in athletic and greater physical domains.

Keywords: Physics, Baseball, Pitching, Curveball, Fastball Changeup, Slider, Spin, Kinematics, Runge-Kutta, Binary Search, Python

Contents

1. Introduction

1.1. Background

Above effective strategy and solid player fundamentals, gaining a competitive edge in the game of Baseball involves leveraging Physics principles. Most plays begin with a hitter, or batter, facing off against a pitcher. The pitcher attempts to throw a pitch to the hitter with the goal of maintaining accuracy (hopefully to throw the ball in the strike zone). However, pitches in the strike zone are more easily hitable, thus pitchers have resorted to adding additional movement to pitches to deceive a hitter's perception. This effect is accomplished by managing spin applied to the ball at release.

The best-known pitch with enhanced movement is the curveball – a pitch thrown with topspin to dive towards the earth faster than with gravitational acceleration alone. Other deceptive pitches include the slider, which dives down and away from a right-handed hitter, and the changeup, which drifts into a right-handed hitter though often thrown with lower speed. Even the most common pitch, the fastball, is defined by its spin – the backspin allows the ball to fall towards the earth at a rate slower than pure gravitational acceleration.

The core objective of this project is to precisely model the movement of such pitches, down to the granularity of several key parameters. This task involves building the appropriate simulation model and visualization methods to analyze pitch movement in various scenarios, accurate to real-world behavior.

1.2. Research Question

In Baseball, three key pitching achievements are regarded as the ultimate frontier of pitching abilitiy. These dream-catching pitch deliveries are the

1. **"Rise"-Ball**: a pitch thrown with a fastball grip, that itself

curves upward through the air while still intersecting the strike zone.

2. **"Dive"-Ball**: a pitch thrown with a curveball grip, that traverses vertically across the entire strike zone. That is - with appropriate spin, a lower-corner strike is called, but without any spin, an upper-corner strike is called.
3. **"Drift"-Ball**: a pitch thrown with a slider grip, that traverses horizontally across the entire strike zone. Similar to the "Dive"-Ball, with appropriate spin, an outside-corner strike is called, but without any spin, an inside-corner strike is called (with a right-handed pitcher and hitter).

This project will objectively determine, in a reproducible and parameter-defined setting, the minimum physical abilities necessary to achieve each of the above pitch deliveries; furthermore, if the extent of such abilities are achievable by human players who can produce such pitches in a real-world game setting.

In concise and objective terms, this project will answer:

1. What combination of pitch speed, spin rate, and release height are minimally required to throw a **"Rise"-Ball**?
2. What combination of pitch speed, spin rate, and release height are minimally required to throw a **"Dive"-Ball**?
3. What combination of pitch speed, spin rate, and lateral release point are minimally required to throw a **"Drift"-Ball**?

1.3. Motivation and Numerical Approach

As time continues, many players and spectators may claim to posses or have witnessed these pitch deliveries. However, human perceptive biases play a role in these anecdotal conclusions. By embracing a purely numeric approach built upon precise computing methods, the above research question may be clearly, directly, and accurately addressed once and for all.

Additionally, with a foundation in reproducible program execution and simulation tooling, this project has the ability to fine-tune numerous input parameters to several key output parameters, described later in the work.

1.4. Prerequisite Physics Material

As the ball travels throughout the atmosphere, it is subject to acceleration from three major sources: gravity, air resistance (drag), and the Magnus Effect ("Curve" effect resulting from spin). The accelerations are symbolically defined below, with brief intuition included.

1. **Gravitational Acceleration**: Constant "free fall" acceleration, straight downward towards the Earth's center of mass.

$$\vec{a}_G = \left\langle 0 \quad 0 \quad -g \right\rangle$$

$$g \approx -9.8 \text{ m/s}^2$$

2. **Acceleration by Drag**: Acceleration experienced in the direction immediately opposite of movement. Velocity has second-order influence.

$$\vec{a}_D = \frac{-1}{2m} C_D \rho A |\vec{v}|^2 \hat{v}$$

$$C_D = \text{Drag constant experimentally found to be .40}$$

$$A = \text{Cross-sectional area of ball, m}^2.$$

$$\rho = \text{Atmospheric (fluid) density, Kg/m}^3.$$

$$m = \text{Ball mass, Kg.}$$

3. **Acceleration by Magnus Effect**: Acceleration occurring perpendicular to direction of movement (note cross product between velocity and angular velocity). Similar to drag, velocity has second-order influence, but contributions of angular velocity are diminishing.

$$\vec{a}_M = \frac{1}{2m} C_M \rho A |\vec{v}|^2 (\hat{\omega} \times \hat{v})$$

$$C_M = \text{Magnus constant experimentally modelled by } .39S^{.31}$$

$$S = \frac{2\pi r |\vec{\omega}|}{|\vec{v}|}$$

$$\vec{\omega} = \text{Angular velocity of ball, rad/s.}$$

1.5. Literature Review

Below are three critical resources with relevant Physics material and computing application innovations that inspired this work.

1. Aerodynamics of Baseball, NASA. (3).
This source derives and applies kinematic formulas in the context of Baseball. The site contains several pages going into medium detail with regards to drag on a sphere, lift and drag on a baseball, trajectories of curveballs and fly balls, ideal flow, and ballistic flight. Despite the complete breadth of these topics that even fall outside the direct scope of this project, NASA presents an informative foundation to many of the end principles. For example, in the discussion of drag on a baseball versus an ideal sphere, the Reynolds number (inertial force divided by viscous force of air immediately surrounding the ball's surface) is explored, even though it is concluded that nearly all human-thrown baseballs share a constant Reynold's number. Finally, this site is a portal to several graphical simulations, titled "Curve Ball", "Curve Ball Expert", "Hit Modeler", "Hit Modeler Weather", "Flight Calculator". These models are indeed detailed and in-depth, but are slightly unintuitive and require manual experimentation to answer specific questions such as the ones posed by the project's introduction.

2. The Physics of Baseball Pitching, University of Texas. (2). This source is a math-dense explanation of a baseball's curving tendencies, going as far as suggesting methods for building smoothly integrated simulations. The physics content is fully vectorized and in agreement with that of the NASA site (1). One slight difference noted is a small discrepancy in empirically defined constants, such as the drag coefficient. One new addition of this site is its discussion of ODEs to solve the presented set of equations. The source solves for the update in position and velocity with respect to each axis using fourth-order Runge-Kutta, but this derivation is a little unclear. Later on, this project derives position and velocity themselves from acceleration to avoid this confusion of approach. Finally, this source inspects a truly deceptive pitch left out in this proposal: the knuckle ball, a pitch with zero spin that moves unpredictably by turbulent flow in the atmosphere. Even though this pitch and its physical behavior is outside the scope of this project, this information is still productive and gives a more precise depiction of the variables at play in the simulation.
3. The Effect of Air on Baseball Pitches. (4). This source is a concise piece tying together all aspects that affect baseball movement through the air. The page begins with a clear and intuitive description of an appropriate coordinate space, which this work uses as inspiration to model physical space within my own simulation. Especially insightful are the plots illustrating change in motion for different pitches, as this is a type of plot leveraged in this project from several insightful angles. Lastly, the piece is presented as a lesson, with each step logically introducing the next. The author even includes reading questions that emphasize key ideas or prompt for computation practice to reproduce or apply the derived steps. Before embarking on implementation, these problems were independently solved to yield a more complete understanding of the source's approach to this project.

2. Methods

2.1. Problem Formulation

Before proceeding with the core simulation model, the problem must be clearly and consistently articulated. Insights and Analysis surrounding the research questions will arise by tracking a baseball's flight from the pitcher's release until the moment of intersection with the plane formed at the front of home plate. At each sample point, ball position, velocity, and acceleration are saved and stored in a time series data structure. Later on, this data structure, technically implemented as a Pandas DataFrame object, can be inspected and compared between simulation episodes.

With the simulation modelling a real-life game situation, a 3 dimensional coordinate system is established. The $\vec{x}$ axis moves positively from the pitching mound towards home plate. The $\vec{y}$ axis moves positively from the pitching mound in the direction of first base, perpendicular to the $\vec{x}$ axis. Finally, the $\vec{z}$ axis is absolute ($z = 0$ signifies ground), spanning directly upwards away from the Earth's center of mass. The origin of this system occurs at the front of home plate, at its horizontal center, on the ground. For greater clarity, this implies that the pitching mound occurs at a negative x coordinate, designed as such so that the ball always moves with positive velocity in the $\vec{x}$ direction.

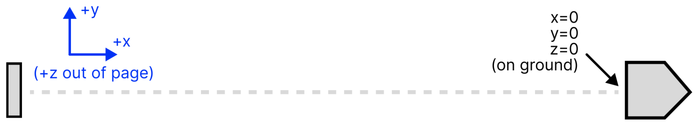

Figure 1: The simulation world frame illustrated between the pitching mound and home plate

Furthermore, the simulation will rely on pre-defined spin angles for the four inspected pitches: fastball, curveball, slider, and changeup. These spin angles each denote the unit direction of the corresponding $\vec{\omega}$, the angular velocity vector. Intutively, the direction of spin can be understood from a given $\vec{\omega}$ by applying the "Right Hand Rule". The spin angles (assuming a right-handed pitcher) utilized in this project are as follows:

1. Fastball: direct backspin.

$$\hat{\omega}_{\text{fastball}} = \begin{pmatrix} 0 & -1 & 0 \end{pmatrix}$$

2. Curveball: topspin with slight clockwise tilt.

$$\hat{\omega}_{\text{curveball}} = \begin{pmatrix} 0.196 & 0.981 & 0 \end{pmatrix}$$

3. Slider: topspin similar to curveball, with greater clockwise and upward tilt for greater intended horizontal movement (away from right-handed hitter).

$$\hat{\omega}_{\text{slider}} = \begin{pmatrix} 0.408 & 0.408 & 0.816 \end{pmatrix}$$

4. Changeup: backspin similar to fastball, with spin also occurring towards the right for intended movement towards a right-handed hitter.

$$\hat{\omega}_{\text{changeup}} = \begin{pmatrix} 0.100 & 0.995 & 0 \end{pmatrix}$$

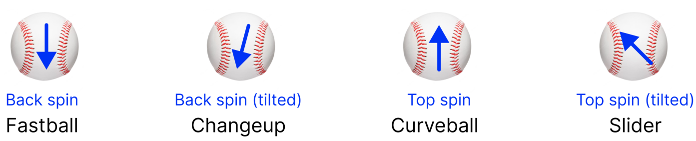

Figure 2: The four pitch grips and their respective spin angles visualized, from a top-down view

Adding onto these world-frame definitions and constants, the following parameters are established and intended to be tuned for simulation experimentation.

1. **Initial Position**: The pitcher's release point of the ball. For the experiments leveraged in this project, the initial position is considered to be $\begin{pmatrix} -54 & -1.5 & 7 \end{pmatrix}$ ft.

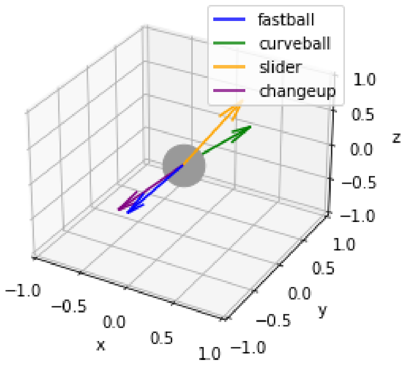

Figure 3: Similar to Fig 2, the pitch spin angular velocity unit vectors ($\hat{\omega}$) relative to the established world frame

2. **Initial Speed**: The ball's speed when released by the pitcher. Note only the initial speed is specified because the simulation begins at pitch release, and one can expect the ball to slow down throughout its flight by the effects of drag.
3. **Horizontal Release Angle (HRA)**: The pitcher's release angle parallel to the $\vec{x}, \vec{y}$ plane (parallel to the ground). This parameter is used for aiming.
4. **Vertical Release Angle (VRA)**: The pitcher's release angle parallel to the $\vec{x}, \vec{z}$ plane (up and down, from the pitching mound to home plate). Like HRA, this parameter is used for aiming.
5. **Forward Arm Angle (FAA)**: The angle of the pitcher's arm at the moment of release parallel to the $\vec{x}, \vec{z}$ plane, with FAA=0 signifying the arm is vertical (strictly follows the span of $\vec{z}$) when the ball is released (no vertical tilt towards home plate).
6. **Side Arm Angle (SAA)**: The angle of the pitcher's arm at the moment of release parallel to the $\vec{x}, \vec{y}$ plane, with SAA=0 signifying the arm is horizontal and perpendicular to $\vec{x}$ (strictly follows the span of $\vec{y}$) when the ball is released (no side tilt towards home plate).
7. **Ball Spin**: the balls spin direction and magnitude expressed by the corresponding angular velocity vector $\vec{\omega}$.

2.2. Pitch Simulation

Using the above defined parameters as the basis description of each simulation episode's starting state, a few more state descriptors are established by compounding such input parameters. Ball velocity, $\vec{v}$, is found by applying initial ball speed in the direction of the HRA and VRA, subsequently converting the cylindrical frame to the greater Cartesian system. Also, the ball spin vector is redefined relative to the world frame by similarly transforming $\vec{\omega}$ by the FAA and SAA. At this point, the effect of each describing parameter is in the Cartesian world frame, the initial state of the simulation is set, and forward propagation may commence.

To maintain precision while propagating forward in time, an infinitesimal time step, Δt is theoretically ideal, though impractical in computing methods due to the resulting infinitesimal

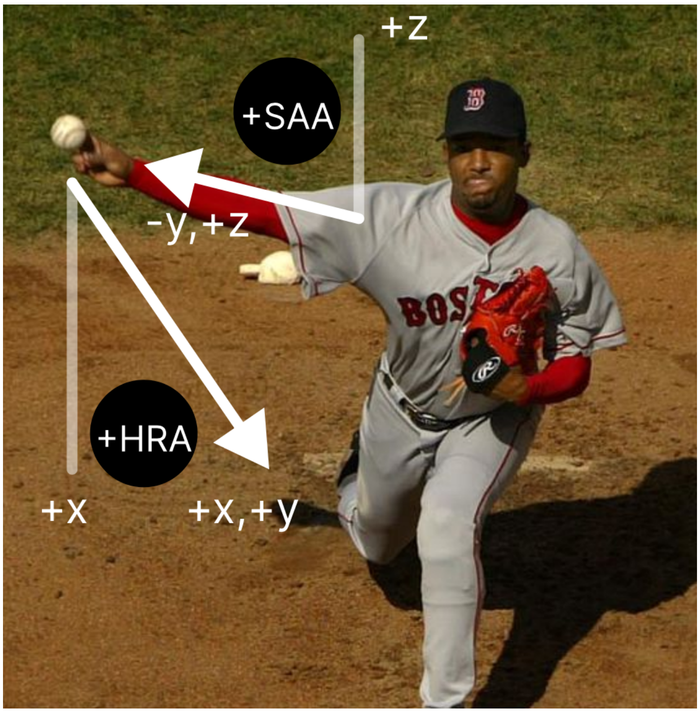

Figure 4: The Side Arm Angle (SAA) and Horizontal Arm Angle (HAA) aiming parameters visualized from a top-down view, embedded within the world frame

update. Thus, $\Delta t = 0.05$ seconds is established to retain accuracy while still allowing for reasonable simulation run time (fewer than 10s), as numerous simulations will be run in sequence later on when searching for optimal input parameters. Note that with respect to the forward propagation method, the Leapfrog Method is not necessary since simulation backward in time will not occur, thus energy does not explicitly require conservation within the scope of our research question, especially when actors external to the ball (atmosphere) are heavily involved and influential to ball movement.

To update ball position, velocity, and acceleration with each time step, the **Runge-Kutta 4^{th}-order (RK-4)** approach to initial-value differential equations is implemented. This method consists of defining a differential equation f that returns, or models, the time derivative of the quantities used to support the variable updated. In this case, that is $f(\vec{v}, \vec{\omega}, t) \to \frac{d\vec{v}}{dt}$. Then, these differential quantities are applied along a series of interpolated estimations (more specific and informed than purely Euler's method) to produce a precise update for ball position, velocity, and acceleration. The RK-4 method is regarded as an industry standard, thus its use in this project is widely justified.

More concretely, let f observe the ball's current velocity, spin (angle and magnitude), and current time step to produce the ball's estimated acceleration resulting from the acting effects of gravity, drag, and the Magnus Effect.

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

Because kinematic laws define velocity as the time integral of acceleration and position as the time integral of velocity, the

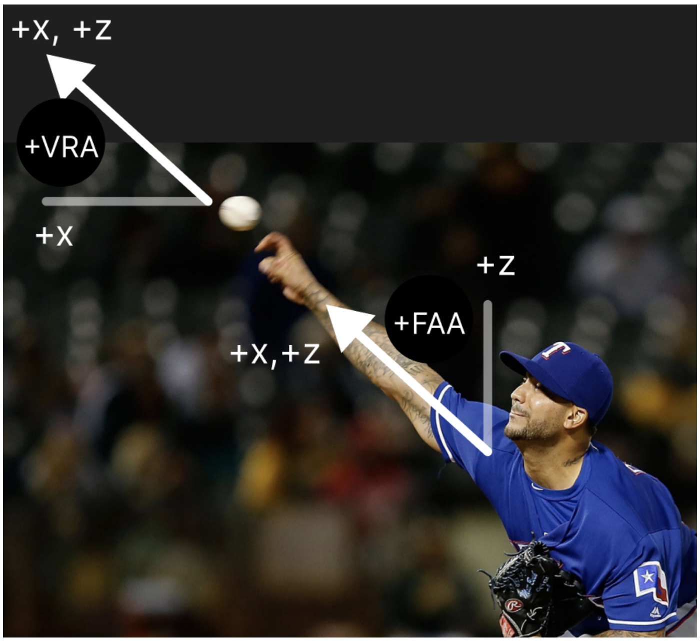

Figure 5: The Vertical Release Angle (VRA) and Forward Arm Angle (FAA) aiming parameters visualized from a side-down view, embedded within the world frame

update for velocity must occur first before position can be updated. In other words, the double integration process must occur in the proper sequence.

The new current acceleration is generalized to the result of $f(\vec{v}, \vec{\omega}, t)$.

To update velocity, define intermediate values $k_{*,\vec{v}}$ to represent approximations for changes in velocity interpolated between t_i and t_{i+1}. Finally, combine these differences and apply additive to current velocity to compute the new velocity.

To update position, similarly define intermediate values $k_{*,\vec{x}}$ to represent approximations for changes in position interpolated between t_i and t_{i+1}. Combining these differences and summing with current position yields the new position estimate.

Below are the steps illustrated as an algorithm.

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

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

2.3. *Method Validation and Real-World Benchmarking*

To clearly illustrate the correctness of this simulation model before continuing to the research questions, 3-dimensional visualization plots are produced for each pitch type.

At this point, reasonable values for the set of initial input parameters are brainstormed as a sanity check.

To further ensure correctness, real-world Major League Baseball (MLB) pitching metrics are obtained to reproduce pitch movements by top-league pitchers. Two datasets from the last complete season (2022) are obtained from Baseball Savant, by MLB (1). The first expresses pitch speed metrics, including average speed for each pitch type in the pitcher's arsenal. The second expresses pitch spin metrics, including average spin rates for each pitch type in the pitcher's arsenal. Pitch grips and angle of spin are maintained by the previously formed assumption. With this data in hand, pitches are simulated according to the fastball, curveball, slider, and changeup of league-leading speed and spin.

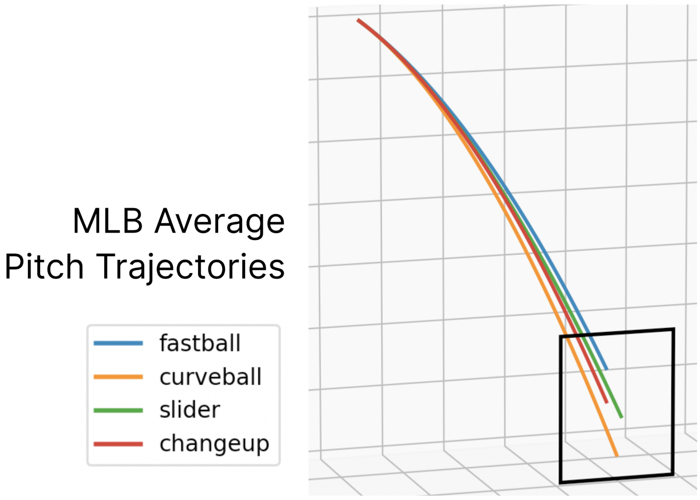

Figure 6: Pitch trajectories from release to strike zone intersection for the average MLB fastball, curveball, slider, and changeup

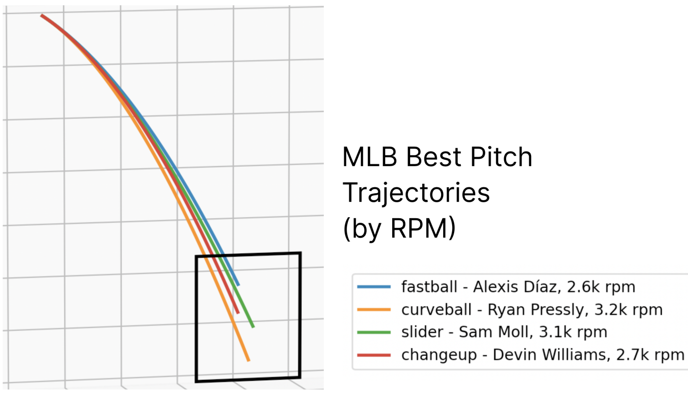

Figure 7: Pitch trajectories from release to strike zone intersection for the top-spin (most deceiving) MLB fastball, curveball, slider, and changeup. Pitcher names are displayed for credit and validation

Since the resulting plots indicate accurate reproduction of pitch movement, the underlying methods are validated and the research questions may be investigated with this pitch movement model as a foundational tool.

2.4. *Solution Search and Optimization*

Thoroughly answering the research questions involves the discovery of optimal physical input parameters to the simulation model, not just parameters that result in the target scenario (”Rise”-Ball, ”Dive”-Ball, ”Drift”-Ball).

The **Binary Search** algorithm acts as an effective starting point to uncover these solutions. However, a few adjustments must be made to this algorithm to comply with the project's objectives.

Firstly, Binary Search fundamentally operates in a one-dimensional observation domain to solve for a secondary variable; our problems involve searching across two-dimensional spaces for a third variable. More precisely, in the case of the ”Rise”-Ball and ”Dive”-Ball, a minimal RPM measure is mapped across a grid of pitch speeds and release heights. For the case of the ”Drift”-Ball, this grid consists of pitch speed versus lateral release point. Thus, Binary Search must be applied for each grid point, treating the input parameters describing that grid point as constant.

Secondly, the nature of our simulation task enables unstable upper and lower boundaries. That is, whenever RPM is adjusted as an input, aiming parameters such as HRA, VRA, FAA, and SAA must be adjusted accordingly. This disrupts the direct computation for minimal RPM, as tuning this value then requires aim to be tuned, again requiring RPM to be tuned, and so on. Thus, Binary Search is adapted to exponentially reduce the search space as usual, with the added detail of restarting the Binary Search operation on more suitable boundary points if a solution is found, though detected to be sub-optimal. The below pseudo-code illustrates this adaptation of Binary Search, referred to as Nested Binary Search:

1. Define lower and upper bound for ball spin (RPM). Because the search space decays exponentially and convergence is guaranteed to occur in this case if a solution exists (because ball end position is continuous), it is sufficient to deliberately initialize extreme boundaries.
2. Determine the best-case aim to satisfy the target scenario, using Binary Search. Tune HRA, VRA, FAA, and SAA as mentioned above so that the ball achieves the desired behavior.
   (a) Terminate eagerly (preempt further algorithm execution) if the target scenario is detected to be physically unreachable. For instance, if the ball already ends above the strike zone, and is not rising for the given RPM, a rise ball is not physically possible by simply changing aim.
   (b) Define new lower and upper bound aiming parameters, preparing for recursive call.
   (c) Recurse towards solution by continuing Binary Search algorithm.
3. If the target scenario is found, and is thus physically reachable, but not minimally (“barely”) reachable, recurse on the partitioned parameter space where exertion (measured in ball spin, RPM) can be safely reduced.

This ”Nested” Binary Search variant is necessary, for example, to not only ensure that a “Rise” Ball can occur by a solution RPM and its simultaneous aiming configuration, but that those solutions are themselves the minimum necessary to “barely” rise the ball when intersecting the strike zone.

The result of applying Nested Binary Search for RPM across specified input grids is a density plot, or ”heatmap”, of the minimally necessary spin rates to achieve the delivery of a ”Rise”-Ball, ”Dive”-Ball, and ”Drift”-Ball. These heatmaps convey not only the human abilities necessary for such pitch deliveries, but suggest patterns that reflect and support the underlying Physical principles.

3. Results

Originally, the objective of this project was established as determining the human output requirements (i.e. ball spin requirements) to successfully deliver a ”Rise”-Ball, ”Dive”-Ball, and ”Drift”-Ball. Having run the above search algorithm across reproducible simulation episodes, the following heat plots present the final results.

In summary, for all three cases, the required human RPM output is much higher than reasonably attainable. This does not imply physical implausibility, but such spins can only be generated by assistive machines, or robots, keeping the object and all other variables constant.

Even though this truth is revealed, each resulting heatmap nonetheless provides an important perspective on the relationships between release position, pitch speed, and rpm to succeed in each target scenario. Below, each scenario is inspected in detail.

3.1. *”Rise”-Ball*

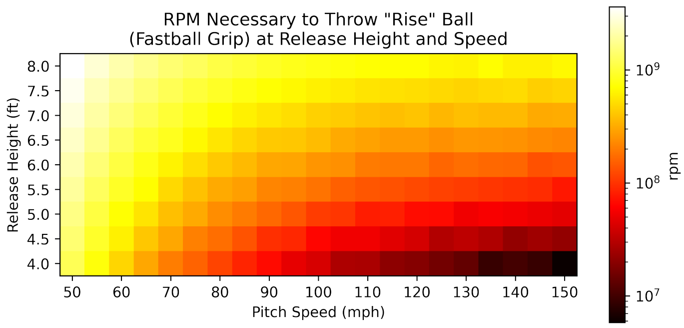

Figure 8: RPM requirement to deliver a ”Rise”-ball for a given pitch speed and vertical release height

As pitch speed increases, starting from an easily-achievable 50 MPH to the humanly impossible level of 150 MPH, the effect of release height becomes increasingly insignificant. That is, release height has a great effect at slow speed, but effectively becomes a non-factor at the upper end of the pitch speed spectrum. This is because with a slower delivery, gravity has a greater period of time to cumulatively accelerate the ball downward, which creates a need for a quadratically greater required upward acceleration induced by spin to overcome gravity and produce lift.

Note that to deliver a "Rise"-Ball, the required ball spin output is much higher than in the case of the "Dive"-Ball and "Drift"-Ball because immense backspin is necessary to not only match, but overcome the powerful effects of gravity and its unavoidable downward acceleration on Earth's surface.

This simulation experiment defines a constant strike zone frame, though in reality, the vertical height and offset of the strike zone adjusts with the batter (knees-to-chest). Applying analogous reasoning to releasing the pitch from a greater height, greater RPM is required to deliver a "Rise"-Ball to shorter hitters compared to taller hitters.

3.2. "Dive"-Ball

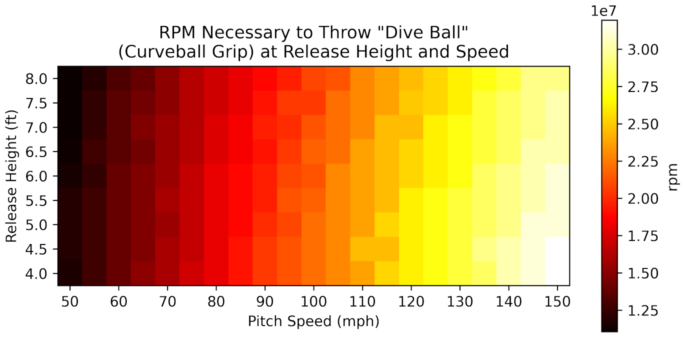

Figure 9: RPM requirement to deliver a "Dive"-ball for a given pitch speed and vertical release height

Across the entire pitch speed spectrum traversed and tested, release height does not play a significant effect in required RPM to deliver a "Dive"-Ball. Instead, pitch speed itself is the primary contributing factor. Additionally, the relationship between pitch speed and required RPM is modelled as linearly positive. This is a unique result since the "Rise"-Ball and "Drift"-Ball's required RPM inputs change roughly exponentially with respect to change in either input parameter (pitch speed or ball release position).

Unlike in the case of the "Rise"-Ball, the horizontal width and offset of the strike zone is constant and independent of the hitter. This implies that the specifications of a given batter, such as height, do not affect the feasibility of delivering a "Rise"-Ball to such hitter.

3.3. "Drift"-Ball

One notable takeaway from the "Drift"-Ball's simulation experiment is that releasing the ball further in the $-\vec{y}$ direction results in a lower ball spin (RPM) requirement because the induced Magnus Effect must only reproduce a smaller horizontal release angle difference.

In concrete terms, the "Drift"-Ball (released from a right-handed pitcher) begins its path as if moving through the strike zone's inside corner (to a right-handed batter), but curves during its flight to intersect the plate at the strike zone's outside corner. In the extreme case of a pitch release point far in the

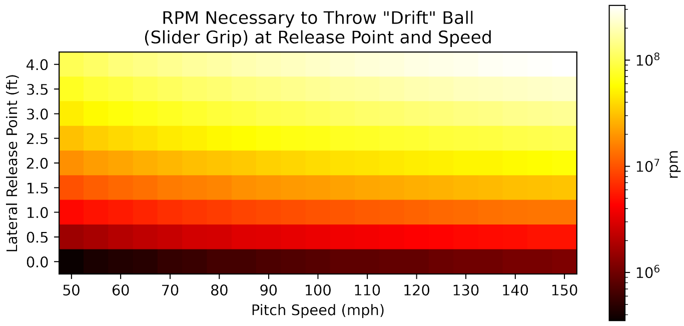

Figure 10: RPM requirement to deliver a "Drift"-ball for a given pitch speed and horizontal release point

$-\vec{y}$, perhaps near third base, the angle between a direct path to the plate's inside and outside corners becomes negligible. Thus, less curve, resulting from spin, is required as the ball is released further in the $-\vec{y}$ direction.

By contrast, as the ball is released further along the $\vec{y}$ direction, the spin applied to the ball by the pitcher must overcome a more significant difference in horizontal release angle if spin were not involved, making throwing a pitch at such spin rate (RPM) even more infeasible by humans, and raising the requirement for a more powerful theoretical pitching machine.

4. Summary and Conclusions

This project aims to determine the minimum pitching abilities (ball spin rate, RPM) required to produce three mythically pitches. The "Rise"-Ball is a pitch crossing home plate as a strike, rising across the front plane as it does so. The "Dive"-Ball begins its trajectory shooting for the top edge of the strike zone, but dives downward to end at the bottom edge of the strike zone. The "Drift"-Ball begins its trajectory shooting for the inside edge of the strike zone, but drifts horizontally to end at the outside edge of the strike zone. In each of the three above target scenarios, ball movement manipulation is required by applying spin.

Numerically evaluated by applying Nested Binary Search across a physically-precise ball movement simulation, the required ball spins (RPM) fall significantly outside the human-achievable range by up to six orders of magnitude (x1000000). Still, the patterns that arise from how RPM requirement changes with respect to the input parameters highlights and reflects the underlying Physical laws governing the problem environment.

Interestingly, the real-life occurrence of these three pitch deliveries have been claimed to be witnessed. By the unbiased, purely analytical findings of this project, it is possible that the observation of such a delivery is affected by the biases of human perception. Further, since the curving movement of a baseball is artificial, humans may pay greater attention to the effect and place greater attribution to pitch spin with regards to hitter deception and batting difficulty. This is supported by baseball game broadcasts and videos showcasing eye-catching pitch movements that may appear, for instance, to rise while crossing the plate. However, the intentional camera angle, incomplete user depth-perception, and other perception-influencing factors create the illusion of a true "Rise"-ball. This idea is illustrated by the initial plots presented in this piece, demonstrating maximal pitch movement by top ball-spin producing pitchers in Major League Baseball, which falls far from the extreme effects of the three investigated pitch deliveries.

Looking forward, this project and its methods bring several impacts and research opportunities. The effects of spin, or the greater Magnus Effect, is not limited to the game of Baseball. Within athletics, the strategic and intentional application of projectile spin is required to gain a competitive edge when delivering:

1. a deceptive, high movement Table Tennis (Ping-Pong) service
2. a maximum-speed Volleyball service that remains in bounds
3. a Tennis return that stays optimally close to (above) the net
4. a Soccer penalty kick that curves its trajectory out of the goalkeeper's reach

and the list continues. Using the experiment and simulation setup defined in this project, parameters and constants (ball/projectile specifications and properties, world frame, etc) can be adjusted to easily and simply adapt to surrounding research questions in the realm of computationally-driven athletic performance.

Outside of athletics, the Magnus Effect plays a key role in upholding many physical achievements, such as aircraft development. Though these phenomena still produce an air pressure separation to induce lift, the notion of spin is not centrally integrated like the research methods highlighted in this project. Nonetheless, since the simulation model forward-propagates kinematic measurements over time, if new acceleration components are computationally defined and integrated to the base f function, this project's methods can be applied towards spinless scenarios as well.

In conclusion, though this project is aimed to solve specific research questions surrounding pitch movement in Baseball, its implications and refined methods serve as a foundation for greater experimentation and research across domains of physical movement.

5. Code Deliverables

The codebase to reproduce these experiments can be found at this GitHub Repository. The main.ipynb contains core logic in modular cells of Python code. To request repository access, email the project author: Blake Sanie, bsanie3@gatech.edu.

References

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