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Using Pitch Analytics to Prepare for Baseball Games at Altitude

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Abstract: The U.S. Air Force Academy baseball team faces unique challenges pitching at 7,258 feet, where reduced air density limits pitch movement and decreases swing-and-miss rates. Specifically, we found that fastballs at altitude show 30% less vertical break. Using logistic regression analysis to quantify the differences between low and high altitude games, we found that vertical break most influences swing-and-miss rates at sea level, while horizontal break becomes more important at altitude. In collaboration with the pitching coach, we developed altitude-specific adjustments to grip, release point, and pitch selection to address these differences. These changes aim to enhance home-game performance without compromising success on the road. Currently, our recommendations are being tested in the Spring Baseball Season and are expected to increase swing-and-miss rates at altitude, offering a consistent competitive edge for the team.

Keywords: Pitch Analytics, Altitude Effects, Swing-and-Miss Rate

1. Introduction

1.1 Context and Motivation

The U.S. Air Force Academy (USAFA) baseball team competes in the Mountain West Conference and faces unique challenges playing home games at an altitude of 7,258 feet above sea level. Reduced air density at high altitude alters pitch movement, impacting vertical and horizontal break, pitch velocity, and ultimately swing-and-miss rates. In 2023, the Falcons posted an overall record of 28 wins and 31 losses, including a strong 17-13 mark in conference play. They excelled at home, going 14-5 at Erdle Field, and made a significant run in the Mountain West Championship, reaching the final game before falling 12-9. However, despite their home success, their opponents' swing-and-miss rate averaged just 12% at altitude, compared to 18% during away games at sea level. This discrepancy highlights the environmental obstacles to consistent pitching performance and suggests room for improvement in training. By refining pitching strategies to account for altitude-specific conditions, the Falcons can better translate analytics into actionable improvements, strengthen their home-field advantage, and enhance their competitive presence in the conference.

The primary goal of this project is to use baseball analytics to understand how altitude impacts pitching performance and to develop strategies that improve home wins for the USAFA Baseball team. By analyzing metrics such as induced vertical and horizontal break, pitch velocity, and swing-and-miss rates, this project aims to provide actionable insights to help improve altitude and sea level.

1.2 Problem Statement

Currently, USAFA pitchers have achieved an average swing-and-miss rate of 12% at home, compared to 18% while away. This disparity highlights the challenges pitchers face when competing at altitude, where environmental conditions significantly alter pitch movement and reduce effectiveness. Although it may be possible to improve the home swing-and-miss rate, the team currently lacks the knowledge and tools to identify the specific adjustments needed to optimize pitching performance.

TrackMan, a state-of-the-art pitch-tracking system, provides detailed data on pitch movement, velocity, spin rates, and other metrics. While this technology generates a wealth of information, the current process for analyzing and applying these insights is inefficient and fragmented. Coaches and players are unable to access a centralized, user-friendly platform to leverage these analytics effectively during games or practice sessions. As a result, it is difficult to make timely, data-driven

adjustments that are essential for improving performance, especially during home games at altitude. To address this issue, the project focuses on developing streamlined, actionable solutions using operations research tools.

1.3 Organization

This paper is organized as follows: Section 2 presents the citations and references employed in this study. Section 3 discusses the data and methodology used to complete the analysis. Finally, Section 4 outlines the considerations and next steps of our findings for the USAFA baseball team.

2. Literature Review

To quantify the relationship between pitch metrics and swing-and-miss rates, we found that regression analysis is a suitable method for our study. After further evaluation, we determined that logistic regression is the most effective technique for our needs. This method allows us to quantify the probability of a swing-and-miss given specific pitch characteristics, making it particularly useful for understanding how altitude impacts pitch effectiveness. Logistic regression provides interpretable coefficients that highlight which factors—such as vertical break, spin rate, or velocity—have the greatest influence on swing-and-miss rates at different elevations. By using this approach, we can generate actionable insights that help pitchers make targeted adjustments to their mechanics, ultimately improving performance at altitude. This method helps us gain valuable insights from the data, allowing the USAFA baseball team to enhance their performance in different conditions.

The literature reviewed falls into three primary categories: (1) studies on pitching mechanics and success factors, (2) predictive models for swing-and-miss rates, and (3) machine learning approaches for performance analysis. This structure allows us to connect existing findings directly to our objective of enhancing performance analytics for USAFA's baseball team.

For pitching mechanics, Whiteside et al. (2016) analyze ball speed and release consistency as significant predictors of pitching success, providing valuable insights on the mechanics of pitching that are highly relevant to our analysis of altitude effects. Goldstein's (2023) updated swing-and-miss model further strengthens our approach by incorporating variables such as pitch velocity and location, which align closely with our goal of improving scouting and strategy adaptation for varying conditions. Koseler and Stephan (2017) present a systematic review of machine learning in baseball, supporting our selection of regression techniques by highlighting the efficacy of logistic regression in binary classification scenarios, like predicting swing-and-miss outcomes.

3. Data and Methodology

3.1 Data Collection

The dataset for this project comes from the TrackMan API, which tracks NCAA pitch metrics like velocity, movement, spin rate, and swing-and-miss rates. Using Python, we extracted raw data, structured it into a 114-column table, and selected key features such as pitch velocity, break metrics, and swing-and-miss outcomes. Initial analysis showed that home swing-and-miss rates average 12% compared to 18% away, with fastballs averaging 89 mph and 2100 RPM at altitude. We cleaned the data by removing null values and irrelevant variables to ensure usability for logistic regression modeling.

Figure 1 displays pitch distribution. Two-seam fastballs are the most common (40%, 2,573 occurrences), followed by sliders (25%, 1,526 occurrences). Changeups (10%, 662 occurrences) and curveballs (3%, 203 occurrences) a, while less common pitches like sinkers (423), cutters (216), and four-seam fastballs (119) (less common than traditional two-seam fastball) provide variety. Rare pitches, such as splitters (17) and undefined pitches (6), make up a small fraction. This distribution ensures strong analysis for frequently used pitches while acknowledging limited data for rarer ones.

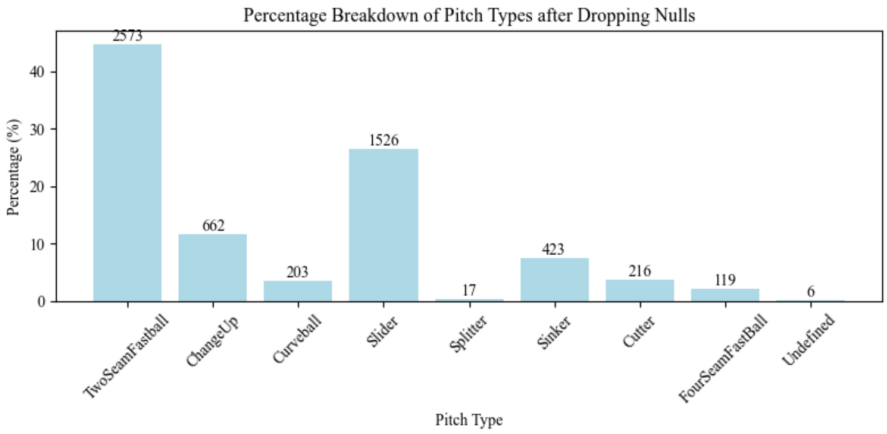

Figure 1. Percentage of Pitch Types in Data Set

3.2 Methodology

We used an initial logistic regression to understand how altitude affects pitching performance and predict successful outcomes. This method works well for binary classification, like predicting whether a pitch will result in a "swing-and-miss." We split our data into training (80%) and testing (20%) sets to check how well our model performs. Key factors we considered included pitch type (e.g. two-seam fastball, curveball, slider), pitch speed (in mph), horizontal and vertical break (which measures pitch movement in inches), and spin rate (the pitch's rotational speed in RPM). Our target variable was whether a swing-and-miss occurred (1) or not (0).

Building on our initial logistic regression model, we refined our analysis by developing a two-step predictive approach to estimate swing-and-miss probabilities more accurately. The first step of our model predicts the probability that a batter swings at a given pitch based on key pitch characteristics such as velocity, spin rate, and movement. This logistic regression model allows us to account for the likelihood of a swing occurring, recognizing that factors like pitch type and location heavily influence a batter's decision to swing. Once we establish the probability of a swing, we use this predicted value as an independent variable in the second step of our model, which determines the probability that the swing results in a miss. By structuring the analysis this way, we ensure that our final swing-and-miss predictions incorporate both the batter's decision-making process and the pitch's effectiveness.

This two-step model provides a more nuanced understanding of how altitude affects pitching performance by isolating the impact of environmental conditions on both batter behavior and pitch effectiveness. By controlling the probability of a swing before predicting the swing-and-miss rate, we reduce potential biases that might arise from differences in hitter approach or game situations. The final predictive tool allows coaches and players to assess how different pitch characteristics interact with altitude and other factors, providing actionable insights for improving performance. These results are integrated into a user-friendly app that will help the USAFA baseball team make data-driven adjustments, ensuring that our model is both practical and aligned with modern sports analytics.

By applying this refined methodology, we developed a predictive tool that provides actionable insights for the USAFA baseball team. This model enables coaches and players to evaluate how altitude impacts pitching effectiveness, isolating mechanical and environmental influences to guide strategic adjustments. Our predictive swing-and-miss metric allows for personalized recommendations, helping pitchers optimize their mechanics based on conditions they will face. This thorough and ongoing process ensures we build a strong model that supports the USAFA baseball team's goals.

3.3 Predictor by Pitch Outputs

Two-seam fastballs, highlighted in Table 1, demonstrate distinct differences in effectiveness between high (all games above 7258 feet) and low altitudes (games below 2000 feet). At high altitude, vertical break has a moderate impact on swing/miss rates (+3.09%), with smaller contributions from induced vertical break (+0.94%) and plate location height (+0.62%). Spin rate shows negligible influence (-0.01%). In contrast, at low altitude, vertical break's impact increases dramatically to +8.59%, making it the most influential feature. Horizontal break (+3.10%) and induced vertical break (+2.70%) also gain prominence, indicating that fastballs benefit more from vertical movement at low altitudes, whereas spin rate and plate location are less significant. This is critical because the fastball is a foundational pitch, setting up other pitch types and challenging batters with speed and movement. Understanding how environmental factors alter its effectiveness enables pitchers

to adjust mechanics to maintain its dominance. Thus, a pitcher who can adjust their mechanics to increase vertical break at altitude has the best chance of increasing their swing and miss rate against batters.

The changeup, in Table 2, exhibits consistent vertical break effects across altitudes, with both high and low altitudes showing a +2.45% impact on swing/miss rates. At high altitude, release speed (+0.92%) and horizontal release angle (+0.81%) contribute marginally, while horizontal break negatively affects performance (-0.55%). At low altitude, additional predictors, such as pitch release side (+1.20%) and outs (+0.72%), gain importance, showing that while vertical break remains crucial, release mechanics and game-state factors play larger roles at low altitudes. Game-state strikes are how many strikes there are when the pitch is thrown. Game-state outs is how many outs there are when the pitch is thrown. The changeup is essential for disrupting a batter's timing and creating deception. By refining the factors that influence its effectiveness at varying altitudes, pitchers can better utilize this off-speed pitch to complement their fastball.

Curveballs, in Table 3, reveal shifts in influential predictors depending on altitude. At high altitude, horizontal break (+1.27%) and spin axis (+0.74%) are most impactful, while vertical release angle has a slight negative effect (-0.06%). At low altitude, vertical break (+1.69%) becomes more critical, with horizontal release angle (+0.81%) and induced vertical break (+0.40%) emerging as secondary predictors. Spin axis has a reduced effect at low altitude (+0.57%). This suggests curveballs rely more on horizontal movement and spin at high altitudes, whereas vertical movement becomes prioritized at lower altitudes. The curveball is pivotal for changing eye levels and disrupting a batter's expectations. Adjusting pitch mechanics for altitude ensures the pitch maintains its sharp break and remains an effective strikeout tool.

Sliders, in Table 4, show significant differences in feature impacts by altitude. At high altitude, horizontal break (+3.93%) and game-state strikes (+1.07%) dominate, with release height contributing minimally (-0.04%). At low altitude, vertical break becomes the most influential factor (+4.23%), along with game-state strikes (+2.35%) and horizontal release angle (+2.18%). Release height shifts from a negative to a positive contributor (+1.25%). These findings indicate that sliders thrive on horizontal movement at high altitudes but benefit from vertical movement and specific release mechanics at lower altitudes. The slider's sharp lateral movement makes it a critical pitch for inducing swings and misses, especially against same-handed batters. Understanding its behavior at different altitudes allows pitchers to maintain its devastating movement and maximize its utility in crucial situation.

Table 1. Two-seam fastballs

Altitude	Predictor	Effect on Swing/Miss Rate (%)
High	Vertical Break	+3.09
High	Induced Vertical Break	+0.94
High	Plate Location Height	+0.62
High	Vertical Release Angle	+0.60
High	Spin Rate	-0.01
Low	Vertical Break	+8.59
Low	Horizontal Break	+3.10
Low	Induced Vertical Break	+2.70
Low	Strikes	+2.22
Low	Plate Location Height	-1.25

Table 2. Changeups

Altitude	Predictor	Effect on Swing/Miss Rate (%)
High	Vertical Break	+2.45
High	Release Speed	+0.92

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High	Horizontal Release Angle	+0.81
High	Plate Location Side	+0.54
High	Horizontal Break	-0.55
Low	Vertical Break	+2.45
Low	Pitch Release Side	+1.20
Low	Outs	+0.72
Low	Pitch Location Side	+0.64
Low	Induced Vertical Break	+0.59

Table 3. Curveballs

Altitude	**Predictor**	**Effect on Swing/Miss Rate (%)**
High	Horizontal Break	+1.27
High	Spin Axis	+0.74
High	Game-State Outs	+0.30
High	Plate Location Side	+0.12
High	Vertical Release Angle	-0.06
Low	Vertical Break	+1.69
Low	Horizontal Release Angle	+0.81
Low	Spin Axis	+0.57
Low	Induced Vertical Break	+0.40
Low	Horizontal Break	-0.34

Table 4. Sliders

Altitude	**Predictor**	**Effect on Swing/Miss Rate (%)**
High	Horizontal Break	+3.93
High	Game-State Strikes	+1.07
High	Horizontal Release Angle	+0.42
High	Vertical Break	+0.29
High	Release Height	-0.04
Low	Vertical Break	+4.23
Low	Game-State Strikes	+2.35
Low	Horizontal Release Angle	+2.18
Low	Vertical Break	+1.31
Low	Release Height	+1.25

4. Next Steps and Considerations

Our analysis highlights how environmental factors, such as altitude, influence pitch effectiveness, providing coaches with precise information on how to adjust strategies for both home and away games. For example, at high altitudes, where pitches tend to break less due to reduced air density, coaches can emphasize mechanics that increase vertical break, such as refining release angles or increasing spin efficiency, to compensate for the environmental impact. For low altitudes, where vertical break has a more pronounced effect, coaches can tailor training to focus on maximizing this feature, such as through drills targeting pitch grip or wrist mechanics.

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By presenting these insights in an accessible format—such as rankings of key features for each pitch type or visualizations of their effects—coaches can create individualized plans for pitchers. For instance, a pitcher struggling with consistent vertical break might benefit from targeted sessions on release mechanics, while another pitcher excelling at spin rate could focus on exploiting that strength in pitch selection. These adjustments not only optimize individual performance but also enable strategic deployment of pitchers during games. For example, a pitcher whose fastball thrives on high vertical break can be prioritized at low-altitude games where this feature is more impactful. This data-driven approach equips coaches to make informed, player-specific adjustments that elevate team performance and maintain a competitive advantage in any environment. The coaching staff has expressed their enthusiasm for the project, with the head pitching coach noting, "This tool will be a game-changer during bullpens, allowing pitchers to analyze their TrackMan data and experiment with different grips and release points to optimize their performance at altitude."

5. Future Work

Our study provides valuable insights into the impact of altitude on pitching performance. Future research could enhance these findings by incorporating factors like humidity, temperature, and wind speed, which also influence ball movement. Expanding the dataset to cover multiple seasons and stadiums would improve model generalizability, while leveraging machine learning techniques, such as neural networks or ensemble methods, could yield more sophisticated predictive models for swing-and-miss rates.

Future work could include incorporating batter-specific tendencies to improve prediction accuracy and tailor pitch sequences. Additionally, integrating biomechanics data—such as release mechanics—would help validate whether recommended adjustments are physically implemented and effective.

6. References

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