DOI: 10.2507/36th.daaam.proceedings.014

APPLICATION OF MONTE CARLO SIMULATION FOR EVALUATING WIND INFLUENCE IN EXTERNAL BALLISTICS

Antonia Galić, Zvonko Trzun & Andrej Razumić

This Publication has to be referred as: Galic, Z[vonko]; Trzun, Z[vonko] & Razumic, A[ndrej] (2025). Application of Monte Carlo Simulation for Evaluating Wind Influence in External Ballistics, Proceedings of the 36th DAAAM International Symposium, pp.0107-0115, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-47-1, ISSN 1726-9679, Vienna, Austria
DOI: 10.2507/36th.daaam.proceedings.014

Abstract

This study investigates the application of Monte Carlo simulation to evaluate the impact of wind on the accuracy and precision of unguided rockets. The influence of constant stochastic wind is modelled with wind direction and intensity as variable parameters. Given that wind has the most significant effect on projectile trajectory deviations and impact point dispersion among atmospheric conditions, accurate modelling and parameter selection are critical for reliable simulation outcomes. The study further explores the effect of different probability distributions on the dispersion of rocket impact points. To this end, two commonly used distributions in external ballistics—the Gaussian (normal) and Rayleigh distributions—are employed to generate random wind direction and intensity. Following Monte Carlo simulations, the resulting data are analysed and compared both analytically and graphically. Results show that the Gaussian distribution yields a more concentrated grouping of impact points around the target compared to the Rayleigh distribution, and that wind indeed has a significant influence on the dispersion of unguided projectile impact points.

Keywords: Monte Carlo simulation; unguided projectile precision; stochastic wind modelling; Gaussian vs. Rayleigh probability distribution; rocket precision.

1. Introduction

In modern military technology and aviation systems, understanding and predicting the influence of weather conditions on rocket performance is of utmost importance. One of the key factors that can significantly affect the trajectory and precision of unguided rockets is wind. Wind is a complex variable that can vary in intensity and direction during the rocket's flight [1]. Therefore, it is interesting to compare simulations of the impact of constant stochastic wind on unguided rockets using different probability distributions. This study addresses two research questions. First, do different probability distributions (used to generate random wind) introduce significant differences in the estimated dispersion of impact points for unguided projectiles [2], [3]. The second research question is whether Monte Carlo simulation can be successfully applied to this specific problem (evaluating the dispersion of trajectories and impact points of unguided projectiles due to wind influence) and whether Monte Carlo provides additional insights compared to a deterministically formulated problem.

Monte Carlo simulation is a widely used method for analysing the effects of multiple disturbances and resulting changes in the observed variable [4], [5]. It is employed when it is impractical to establish a clear functional relationship between multiple input parameters and outcomes that depend on their variations. The method relies on repeated nondeterministic sampling to obtain numerical results, leveraging the stochastic nature of the sample to draw conclusions about processes that may be deterministic in nature. This method has already been used in several studies examining the influence of disturbances on rocket flight [6], [7], but these works did not focus on the impact of wind. Of particular interest are studies [8] and [9], which link wind effects to rocket trajectories, and our paper aims to expand on those findings.

2. Methodology

To address the research questions posed in the Introduction, a Monte Carlo simulation of rocket firings will be conducted. The rocket's characteristics will remain constant, while only the wind speed and direction will vary. The Monte Carlo method is especially suitable when the nature and probability distribution of the variables affecting the outcome (in this case, projectile flight) are unknown [10]. It is also useful for cases where simplifying assumptions (e.g., linearization or normality of the sample) cannot be made in advance, or for analysing samples that exhibit asymmetry, skewness, or kurtosis in their frequency distributions [11].

In this study, the Monte Carlo method is used to generate a large number of random wind samples under different probability distributions. Each simulation produces data on the rocket's trajectory and impact point, including deviation from the target, trajectory elements, and flight time. The results are compared with previously verified data from controlled test firings published in the Firing Table for the specified rocket, serving as a control for the simulation results.

Wind force is scaled using the Beaufort Wind Scale (Table 1).

Force	Description	Wind Speed	Main Effects on Land
0	Calm	< 1 km/h (< 0.3 m/s)	Smoke rises vertically
1	Light Air	1–5 km/h (0.3–1.5 m/s)	Wind direction seen from smoke
2	Light Breeze	6–11 km/h (1.6–3.3 m/s)	Wind felt on face, weather vanes move
3	Gentle Breeze	12–19 km/h (3.4–5.5 m/s)	Leaves and twigs in constant motion
4	Moderate Breeze	20–28 km/h (5.5–7.9 m/s)	Dust raised, small branches move
5	Fresh Breeze	29–38 km/h (8–10.7 m/s)	Small leafy trees begin to sway
6	Strong Breeze	39–49 km/h (10.8–13.8 m/s)	Large branches move, whistling in wires
7	Near Gale	50–61 km/h (13.9–17.1 m/s)	Whole trees move, walking is difficult
8	Gale	62–74 km/h (17.2–20.7 m/s)	Twigs break off trees
9	Strong Gale	75–88 km/h (20.8–24.4 m/s)	Light structural damage
10	Storm	89–102 km/h (24.5–28.4 m/s)	Trees uprooted, significant building damage
11	Violent Storm	103–117 km/h (28.5–32.6 m/s)	Widespread destruction
12	Hurricane	≥ 118 km/h (≥ 32.7 m/s)	Catastrophic destruction

Table 1. Beaufort Wind Scale

For generating random samples, the wind speed is constrained to $|W| < 9.8\ \mathrm{m/s}$, which approximately corresponds to the upper limit of Force 5 on the Beaufort scale. Beyond this threshold, simulation results may become unrealistic, especially if strong crosswinds act on the rocket's trajectory, causing significant deviations from the target. Depending on the type of artillery projectile, wind speed, and the angle at which it acts, the wind's influence can vary. In ballistics, wind is typically decomposed into longitudinal (head/tail) and lateral (left/right) components. Longitudinal wind follows intuitive logic: tailwinds increase range, while headwinds decrease it.

Lateral wind is more complex, affecting the firing direction depending on the projectile type and specific conditions:

- Classical projectiles (and rockets in passive flight) drift downwind (e.g., leftward wind pushes them right).
- Rockets in active flight (with thrust) turn into the wind (e.g., leftward wind causes a leftward turn). Once the motor stops, they behave like classical projectiles. This is due to the centre of pressure being behind the centre of mass, creating a moment that turns the rocket into the wind.

Two series of rocket firings are simulated using Monte Carlo. Each series consists of 1,000 nondeterministically generated initial conditions (ballistic winds). In the first series, wind speed follows a normal distribution, while in the second, it follows a Rayleigh distribution. The Rayleigh distribution is a special case of the Weibull distribution (shape parameter $k=2$) and is commonly used in external ballistics to model wind dispersion.

2.1. Wind Speed Dispersed According to the Normal Distribution

For normal distribution the probability density is calculated as:

$$f(W,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{(W-\mu)^2}{2\sigma^2}} \tag{1}$$

where, in our problem, the independent variable is the wind speed W. This implies that the probability that the wind speed magnitude $|W|$ is less than or equal to a certain threshold W_1 is given by:

$$P(|W| \leq W_1) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-W_1}^{W_1} e^{\frac{W^2}{2\sigma^2}} dW \tag{2}$$

It is evident that the probability in Equation (2) is directly determined by the selected standard deviation σ. Based on the Beaufort scale (Table 1) and empirical data, a value of $\sigma = 5\ \mathrm{m/s}$ is selected for simulation purposes, assuming a normal distribution. By choosing this parameter, it is ensured that, with 95% confidence, the wind speed remains within the range of interest $|W| \leq 9.8\ \mathrm{m/s}$. This also maintains compatibility with results derived from firing tables, which are typically constructed based on test firings conducted under low-wind conditions.

The generated input dataset consisted of 1,000 wind speed values, and the dispersion parameters indicate that the sample was appropriately selected and satisfies the conditions of normality: the mean is -0.11, standard deviation 5.04, kurtosis 0.028, and skewness -0.009. These statistics, together with the histogram confirming visual similarity to the expected frequency distribution, verify that the sample is normally distributed. Figure 1 presents the histogram of total wind speed.

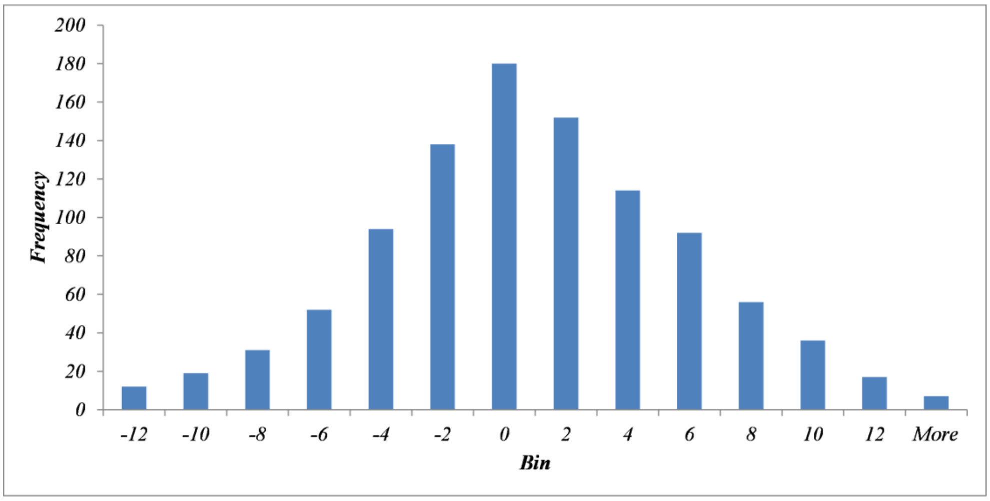

Fig. 1. Histogram of a wind speed sample, distributed according to the normal distribution

In the generated sample, some values significantly exceed the predefined threshold of 9.8 m/s. Such outliers are removed from the input dataset and are not included in the final simulation. A total of 62 such outliers were identified, which slightly exceeds the remaining 5% probability. After outlier removal, the input dataset consists of 938 wind speed values, which are then uniformly decomposed into longitudinal and lateral wind components (as will be explained in Section 2.3).

2.2. Wind Speed Dispersed According to the Rayleigh Distribution

The Rayleigh distribution is a continuous, non-negative probability distribution (it is actually a special case of the Weibull distribution, with shape parameter $k = 2$). It arises in various applications, particularly in the context of signal processing, communications, and physics, where it describes the magnitude of a vector whose components are independent and identically distributed Gaussian random variables. The Rayleigh probability density function is given as:

$$f(W,\sigma) = \frac{W}{\sigma^2} e^{-\frac{W^2}{2\sigma^2}} \tag{3}$$

where the probability that the wind speed W will be less than a certain threshold value W_1 is equal to:

$$P(W \leq W_1) = \int_0^{W_1} \frac{W}{\sigma^2} e^{-\frac{W^2}{2\sigma^2}} dW = 1 - e^{-\frac{{W_1}^2}{2\sigma^2}} \tag{4}$$

It can be seen that, as with the normal (Gaussian) distribution, the shape of the probability density function and cumulative distribution function directly depends on the choice of the parameter σ. It should be emphasized that in the Rayleigh distribution, $\sigma$is a scale parameter and not the standard deviation of the function. The maximum probability density of the above function occurs at the value W_m which is obtained by differentiating the probability density function:

$$f'(W_m) = -\frac{({W_m}^2 - \sigma^2)^2}{\sigma^2} e^{-\frac{{W_m}^2}{2\sigma^2}} = 0 \quad \rightarrow \quad W_m = \sigma \tag{5}$$

while the expected value of this distribution is defined by the following integral:

$$\mu = \int_0^\infty W \cdot f(W) dW = \int_0^\infty \frac{W^2}{{W_m}^2} e^{-\frac{{W_m}^2}{2\sigma^2}} dW = W_m \sqrt{\frac{\pi}{2}} \tag{6}$$

from which it follows that the expected value of the Rayleigh distribution can also be expressed in terms of W_m or equivalently σ as the scale parameter ($\mu \approx 1.253\ W_m$).

The Rayleigh distribution is frequently used in wind energy and meteorological studies to model wind speed, especially in regions where wind direction is uniformly distributed (and this is one of assumptions for our analysis) and speed follows a positively skewed pattern. It is particularly suited for modelling horizontal wind speed when the wind has random direction and its two orthogonal components are normally distributed with zero mean and equal variance σ.

For easier comparison of the effects of two selected probability density function, the scale parameter was set to σ = 4 m/s. This choice ensures an approximately equal 95% confidence that the wind speed remains within the range of interest $W \leq 9.8\ \text{m/s}$. The generated dataset, consisting of 1000 values, was evaluated through descriptive statistics to assess its alignment with the theoretical Rayleigh distribution with a chosen scale parameter. Key statistical indicators were calculated, and the mean (4.96) and standard deviation (2.59) were consistent with the expected theoretical values:

$$\mu[X] = \sigma\sqrt{\frac{\pi}{2}} \approx 5.013, \quad STD[X] = \sigma\sqrt{\frac{(4-\pi)}{2}} \approx 2.538 \tag{7}$$

The sample also exhibited a skewness of 0.537 which closely align with the theoretical values for a Rayleigh distribution, namely 0.631. These results suggest a distribution that is positively skewed and moderately peaked, in line with the Rayleigh profile. The histogram analysis further confirmed the visual similarity between the empirical and theoretical probability density functions (Figure 2).

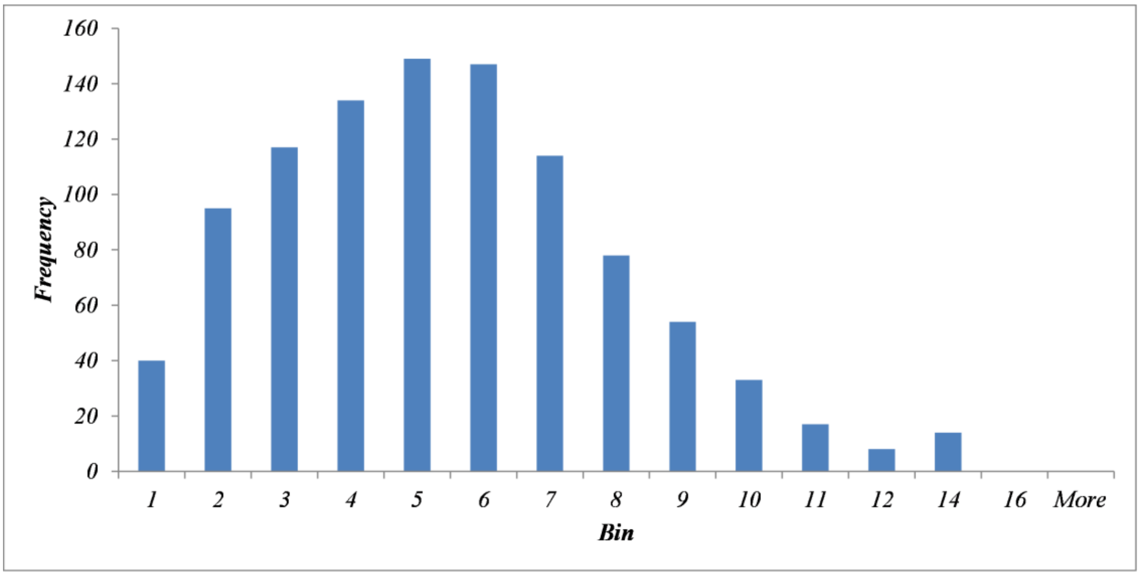

Fig. 2. Histogram of a wind speed sample, distributed according to the Rayleigh distribution

As for outliers (e.g. values where $W > 9.8\ \text{m/s}$) in the generated wind sample 49 cases have been identified (which corresponds very well with the remaining probability of 5%); these winds have been removed from the input wind dataset, leaving the final input set for 951 simulated firing of rockets.

2.3. Wind direction and other simulation parameters

The wind direction in both series is dispersed according to a uniform distribution over the full circle $\phi_W = 0 - 360°$ Since the normal distribution includes negative values, it can be also used with $\phi_W = 0 - 180°$. An alternative approach is to use a half-normal distribution, which contains only non-negative values, while the wind direction is dispersed over the full circle. These two methods ultimately produce very similar or identical results, especially with sufficiently large sample sizes (empirically: $n > 300$). As previously mentioned, lateral wind is particularly hazardous for rocket accuracy, although strong tailwinds or headwinds can also significantly affect the magnitude of the miss distance.

Overall, considering both wind speed and direction, the wind is modelled as a constant stochastic wind. The term “stochastic” is used here due to the nondeterministic nature of the two parameters defining the wind—both variables change from one simulated rocket to another. The term “constant” refers to the fact that once defined, the wind maintains the same direction and magnitude throughout the flight of a single rocket; no changes are introduced with atmospheric layers or as the rocket approaches the target during flight. In external ballistics, this type of wind is also referred to as ballistic wind and is calculated to produce the same effect on the projectile’s trajectory as actual wind varying with altitude and distance to the target would. Regarding other atmospheric parameters, both simulations use the standard ICAO atmosphere (T = 15 °C; p = 1013 hPa; relative humidity Φ = 0%). The only deviation from the standard atmosphere is the presence of wind.

A mathematical 6DOF (six degrees of freedom) rocket flight model was used, which accounts for all influential parameters such as the rocket’s inertial properties, aerodynamic coefficients, initial angles, and others [12].

$$
\begin{aligned}
&\begin{bmatrix} \dot{x} \\ \dot{z} \\ \dot{z} \end{bmatrix} = \boldsymbol{L}_{LP} \begin{bmatrix} u_k \\ \tilde{v}_k \\ \tilde{w}_k \end{bmatrix} \\
&\dot{u}_k = -\tilde{q}\tilde{w}_k + \tilde{r}\tilde{v}_k + \frac{X + F_x}{m} - g\sin\vartheta - a_{Kx} \\
&\dot{\tilde{v}}_k = p_P\tilde{w}_k - \tilde{r}u_k + \frac{\tilde{Y} + F_{\tilde{y}}}{m} - a_{K\tilde{z}} \\
&\dot{\tilde{w}}_k = -p_P\tilde{v}_k + \tilde{q}u_k + \frac{\tilde{Z} + F_{\tilde{z}}}{m} + g\cos\vartheta - a_{K\tilde{z}} \\
&\dot{p} = \frac{(L + L^F)}{I_x} \\
&\dot{\tilde{q}} = p_P\tilde{r} + \frac{-I_x p\tilde{r} + \tilde{M} + \tilde{M}^F}{I_y} \\
&\dot{\tilde{r}} = -p_{PA}\tilde{q} + \frac{I_x p\tilde{q} + \tilde{N} + \tilde{N}^F}{I_y} \\
&\dot{\varphi} = p + \tilde{r}tg\vartheta \\
&\dot{\vartheta} = \tilde{q} \\
&\dot{\psi} = \frac{\tilde{r}}{\cos\vartheta}
\end{aligned}
\tag{8}
$$

This mathematical model also allows the conversion of constant (ballistic) wind into real wind conditions using meteorological bulletins (e.g., Standard Computer Met Message STANAG 4082). However, ballistic wind was intentionally used here to simplify the correlation between a given wind condition and accuracy relative to the target. The simulation modelled the firing of an unguided rocket with a diameter of 122 mm, a length of 2.7 m, and a maximum range of 20,500 m. The target was set at 13,700 m, representing two-thirds of the maximum range, which is a common practice for verifying the correctness of firing tables and mathematical models.

3. Results and Discussion

A sample generated according to the normal distribution is expected to typically show greater clustering around the ideal (mean) value compared to a sample from the Rayleigh distribution. This is because the normal distribution is symmetric around the mean μ, which also corresponds to the highest probability density. Therefore, most of the sample is expected to be tightly clustered around the target location (e.g., approximately 68% of hits are expected, given a sufficiently large sample, within the confidence interval $\mu \pm \sigma$). The dispersion plot of impact points indeed shows significant clustering around the target (Figure 3):

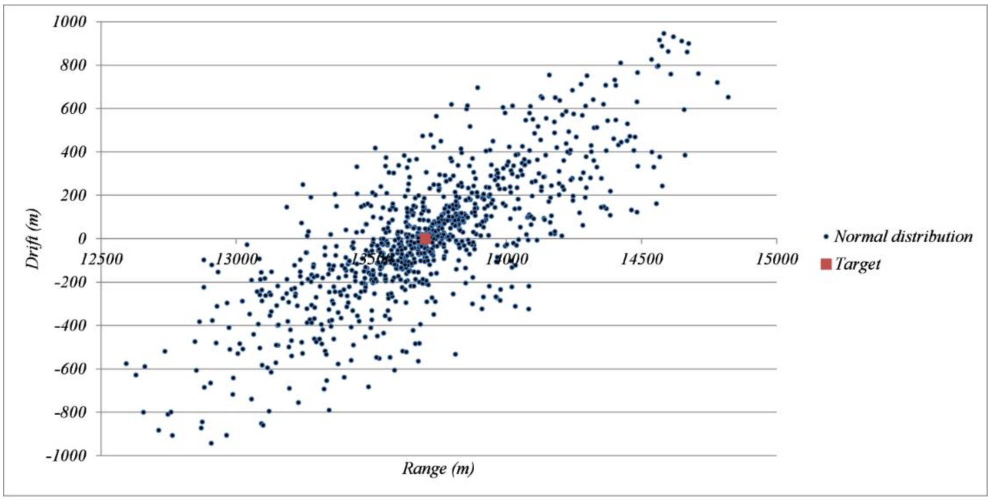

Fig. 3. Effect of normally distributed wind on the dispersion of projectile impact points

The dispersion pattern of impact points appears rotated relative to the firing line (which corresponds to the x-axis on the graph). This is a result of the asymmetry of forces and moments acting on the rocket. The fins at the rear of the rocket are rotated relative to the projectile's axis of rotation for design reasons, which introduces an additional component of Magnus force causing an induced moment and rotation of the dispersion pattern, as shown in Figure 3. The average range is 13,707 m, the minimum range is 12,594 m, and the maximum range is 14,822 m. The standard deviation of the range is 360 m. Regarding lateral drift, the average is 9 m, the minimum is –944 m, and the maximum is 946 m, with a standard deviation of 306 m. Although these elevated deviation values may appear anomalous, they are consistent with the modelling assumption of a uniform wind field - i.e., constant speed and direction throughout the entire trajectory - which does not reflect realistic atmospheric conditions. In practice, a projectile traverses multiple atmospheric layers wherein wind speed and direction vary with altitude (notably, the trajectory apex reaches approximately 2400 m when employing a small drag ring). Despite this simplification, it remains evident that, under high wind shear conditions, the aerodynamic stabilization moments generated by fin surfaces are insufficient to maintain trajectory stability. Consequently, unguided rockets exhibit substantial dispersion and are therefore unsuitable for engagement of point targets, being instead primarily employed in area saturation roles.

A second sample, generated according to the Rayleigh distribution, is expected to exhibit even less clustering around the target location. As seen in the input parameter analysis (Figure 2), the mean and median values are farther from the target compared to the normal distribution. In the Rayleigh distribution, the probability spreads more widely, resulting in a higher frequency of outliers relative to the centre. This issue is not pronounced here because the scale parameter of the Rayleigh distribution was deliberately chosen based on the threshold value (9.8 m/s), rather than another criterion—e.g., to directly compare wind speeds with a 50% probability or similar. Nevertheless, even with this parameter choice, the difference in trajectory dispersion is significant (Figure 4).

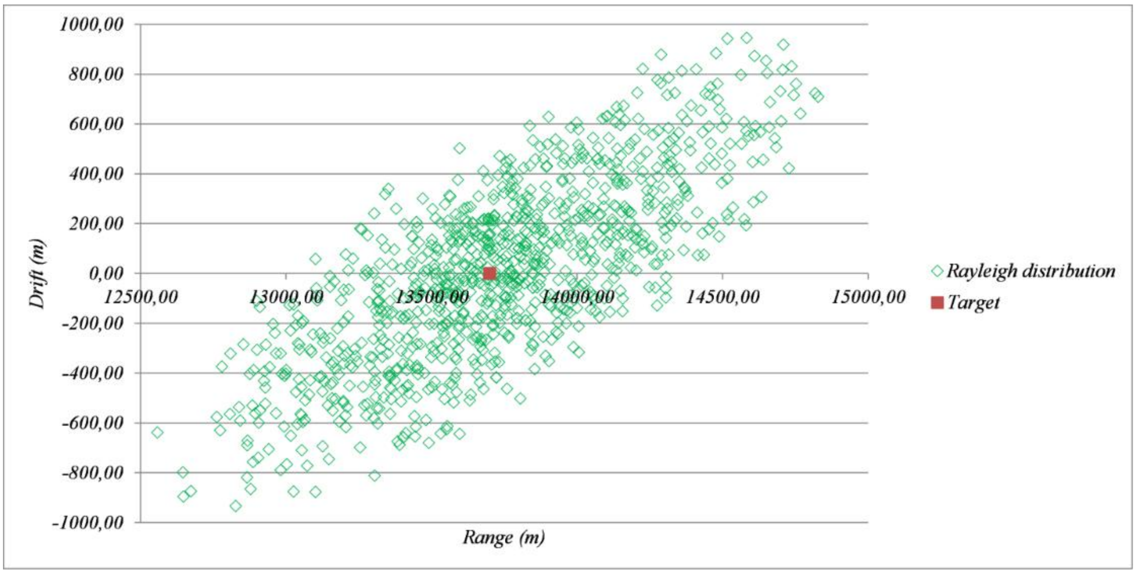

Fig. 4. Effect of Rayleigh-distributed wind on the dispersion of projectile impact points

Even with this stochastically generated wind sample, it can be observed that the dispersion pattern of impact points is rotated relative to the firing line (approximately the x-axis). The imagined trend line closely matches the trend line shown in Figure 3. However, a more important conclusion is that in Figure 4 the dispersion area is significantly less clustered around the target position and more widely spread compared to the sample generated from the normal distribution. The average range is 13,738 m, the minimum range is 12,559 m, and the maximum range is 14,829 m. The standard deviation of the range is 434 m. Regarding lateral drift, the average is 15 m, the minimum is –934 m, and the maximum is 945 m, with a standard deviation of 357 m. It is evident and analytically proven that the scatter is significantly greater. The previously stated conclusion remains valid: the large deviation values result from the imposed strong ballistic wind—assumed constant in both speed and direction along the entire trajectory—which unguided rockets are unable to compensate for through their stabilization moments.

Figure 5 presents both dispersion patterns of impact points together. The dispersion caused by normally-distributed winds is significantly narrower and more concentrated around the imagined trend line (Figure 5):

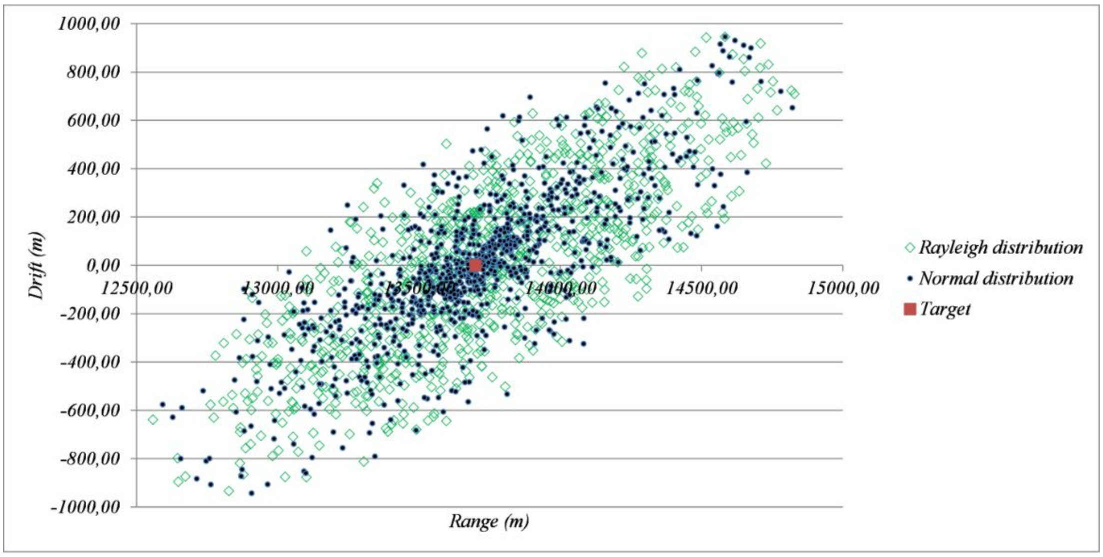

Fig. 5. Comparison of the effect of stochastic wind distributed according to two distributions (Normal vs. Rayleigh)

The displayed images excellently illustrate the value of Monte Carlo simulation. Additionally, Figure 6 shows a deterministically defined boundary line that limits the dispersion area of impact points for the case of maximum considered wind $W = 9.8\,\mathrm{m/s}$. This boundary provides valuable information and demonstrates the magnitude of deviations from the target position that can be expected when firing unguided rockets under such strong ballistic wind conditions.

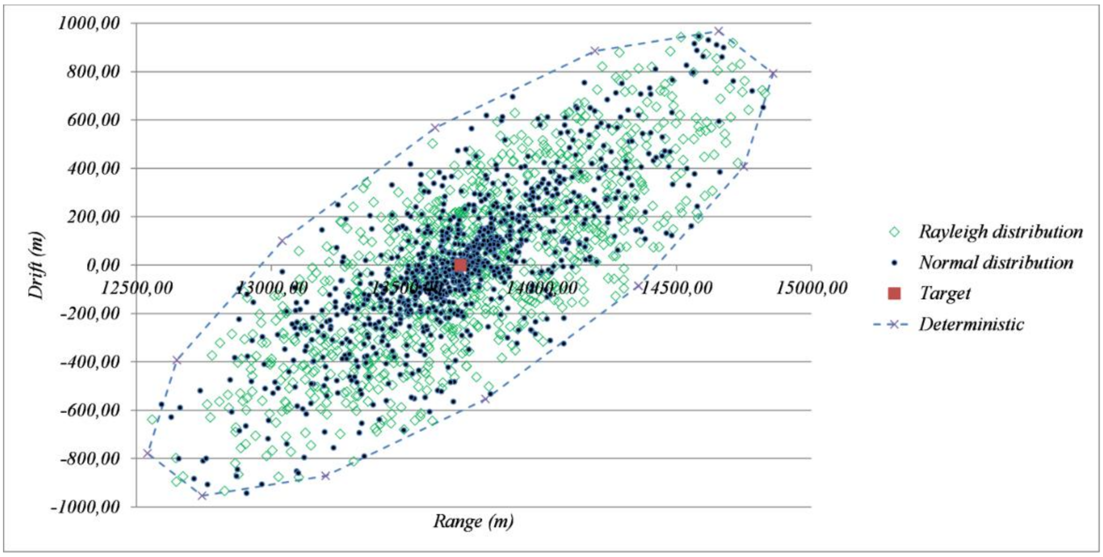

Fig. 6. Comparison of the effect of stochastic wind distributed according to two distributions, together with deterministically defined boundaries for the maximum allowable wind (W = 9.8 m/s)

The deterministically defined boundary clearly indicates the expected limits within which projectile impact points may fall. However, the Monte Carlo simulation provides additional information:

- It offers a statistical overview of the expected impact distribution, showing not only the outer bounds (as given by deterministic analysis) but also the internal structure of the dispersion area. Specifically, it quantifies how many projectiles are likely to impact near the target, forming a dense cluster, and how many will fall closer to the outer, deterministically defined boundary. This enables a much clearer understanding of hit probability within certain zones and supports better risk assessment and operational planning.
- It underscores the critical role of correctly selecting the probability distribution used to generate stochastic wind conditions. As shown in the comparison between normally and Rayleigh-distributed wind samples, the choice of distribution has a profound effect on the resulting dispersion pattern. A poorly chosen distribution can lead to unrealistic assumptions about rocket accuracy or safety margins, while a well-matched model leads to more reliable and actionable predictions.
- It enables probabilistic risk analysis and sensitivity studies, allowing analysts to explore how variations in environmental conditions (such as wind speed and direction) impact the overall effectiveness and precision of unguided rocket fire. This is especially important in operational scenarios where environmental uncertainty cannot be avoided but must be accounted for quantitatively.
- Finally, it bridges the gap between theoretical models and real-world variability, simulating a large number of possible outcomes that reflect the randomness of real atmospheric conditions. This makes Monte Carlo simulation a powerful complement to deterministic modelling, especially when dealing with systems—such as unguided rockets—that are highly sensitive to external perturbations like wind.

4. Conclusion

This study analysed the effect of wind on the dispersion of trajectories and impact points of unguided rockets. Two datasets, each consisting of 1,000 wind samples with stochastically defined speed (intensity) and direction, were generated. The first dataset was based on the normal distribution, while the second followed the Rayleigh distribution. The analysis of the simulation results provided answers to both research questions posed in the Introduction, within the defined scope of this investigation.

First, regarding the choice of the most appropriate probability distribution function, the authors recommend that when assessing the impact of atmospheric factors such as wind, the Weibull or Rayleigh distribution should be used. These functions yield a wider dispersion of impact points around the target, which aligns with empirical data and with the limits defined by the deterministic boundary conditions. On the other hand, for variables that are more controllable—such as manufacturing precision—the normal distribution may be more suitable, as it better reflects the expectation of smaller standard deviations and reduced uncertainty in production quality.

Second, the presented case study also illustrates the value of Monte Carlo simulation. Unlike deterministic models, Monte Carlo provides an additional layer of insight and enables more informed decision-making regarding the appropriateness of methods and acceptable dispersion limits for influencing parameters. The added value of such information has been demonstrated here in the domain of external ballistics of unguided rockets; however, the applicability of Monte Carlo simulation is equally relevant in other branches of physics and mechanics. In particular, Monte Carlo simulations prove invaluable when assessing the combined influence of multiple variable factors, especially when their higher-order interactions are unclear or difficult to model analytically.

The presented study serves as a foundation for further research that will investigate more complex atmospheric conditions, various projectile types, and target hit probability assessment. Future work will focus on extending the atmospheric model by replacing the simplified constant ballistic wind with a layered meteorological model. This enhanced model will incorporate vertical variations in wind speed and direction, as well as the influence of temperature, pressure, and relative humidity. Such an approach aims to achieve a more realistic simulation of environmental conditions affecting projectile flight throughout its trajectory. Additionally, the influence of atmospheric disturbances will be analysed across different projectile types, including variations in geometry, mass, and stabilization methods (e.g., passively stabilized, actively stabilized, and guided projectiles). This will enable a comparative evaluation of sensitivity to environmental perturbations for each configuration, and also the more accurate assessment of effectiveness and reliability of unguided rocket fire under realistic environmental conditions.

5. References

[1] Sun, D.; Liang, X.; Zhao, T.; Fang, H.; Cheng, Z.; Zheng, H.; Zhang, L.; Zhang, F.; Sun, D. & Liu, Y. (2019). Study on large scale projectile impact point positioning method based on trajectory shock wave, Proceedings of the 23rd International Congress on Acoustics, 9–13 Sept 2019, Aachen, Germany, pp. 3346–3353

[2] Hennessey, J. P. J. (1977). Some aspects of wind power statistics, J. Appl. Meteorol., Vol. 16, No. 2 (February 1977), pp. 119–128

[3] Wang, R.; Li, W. & Bagen, B. (2011). Development of wind speed forecasting model based on the Weibull probability distribution, Proceedings of 2011 International Conference on Computer Distributed Control and Intelligent Environmental Monitoring, 2011, Xi'an, China, pp. 2062–2065

[4] Rausch, C.; Nahangi, M.; Haas, C. & Liang, W. (2019). Monte Carlo simulation for tolerance analysis in prefabrication and offsite construction, Autom. Constr.

[5] Ilg, M.; Rogers, J. & Costello, M. (2011). Projectile Monte-Carlo trajectory analysis using a graphics processing unit, Proceedings of the AIAA Atmospheric Flight Mechanics Conference, 08–11 Aug 2011, Portland, Oregon, USA. DOI: 10.2514/6.2011-6266

[6] Hanson, J. M. & Beard, B. B. (2012). Applying Monte Carlo simulation to launch vehicle design and requirements verification, J. Spacecr. Rockets

[7] Trzun, Z. & Vrdoljak, M. (2020). Monte Carlo simulation of missile trajectories dispersion due to imperfectly manufactured warhead, Proceedings of the 31st DAAAM International Symposium, 21–24 Oct 2020, Mostar, Bosnia and Herzegovina, ISSN 1726-9679, ISBN 978-3-902734-29-1, Katalinic, B. (Ed.), pp. 0574–0583, DAAAM International, Vienna, DOI: 10.2507/31st.daaam.proceedings.079

[8] Kenney, W. A. (2017). Improved ballistic wind prediction using projectile tracking data, Ph.D. Dissertation, Old Dominion University, Norfolk, USA

[9] Yao, J.; Wang, X. & Li, J. (2009). Influence on rocket fall points distribution due to random wind, Proceedings of 2009 4th IEEE Conference on Industrial Electronics and Applications, 2009, Xi'an, China, pp. 1860–1863

[10] Miedziński, D.; Głębocki, R. & Jacewicz, M. (2023). Analysis of sounding rocket dispersion using Monte-Carlo simulation, In: Automation 2023: Key Challenges in Automation, Robotics and Measurement Techniques, Szewczyk, R.; Zieliński, C.; Kaliczyńska, M. & Bučinskas, V. (Ed.), pp. 39–50, Springer Nature Switzerland

[11] Chase, K. W. & Parkinson, A. R. (1991). A survey of research in the application of tolerance analysis to the design of mechanical assemblies, Research in Engineering Design

[12] Trzun, Z.; Vrdoljak, M. & Cajner, H. (2021). The effect of manufacturing quality on rocket precision, Aerospace, Vol. 8, No. 6, pp. 160, doi:10.3390/aerospace8060160