GPS Analysis of the 2025 Formula Kite World Championships

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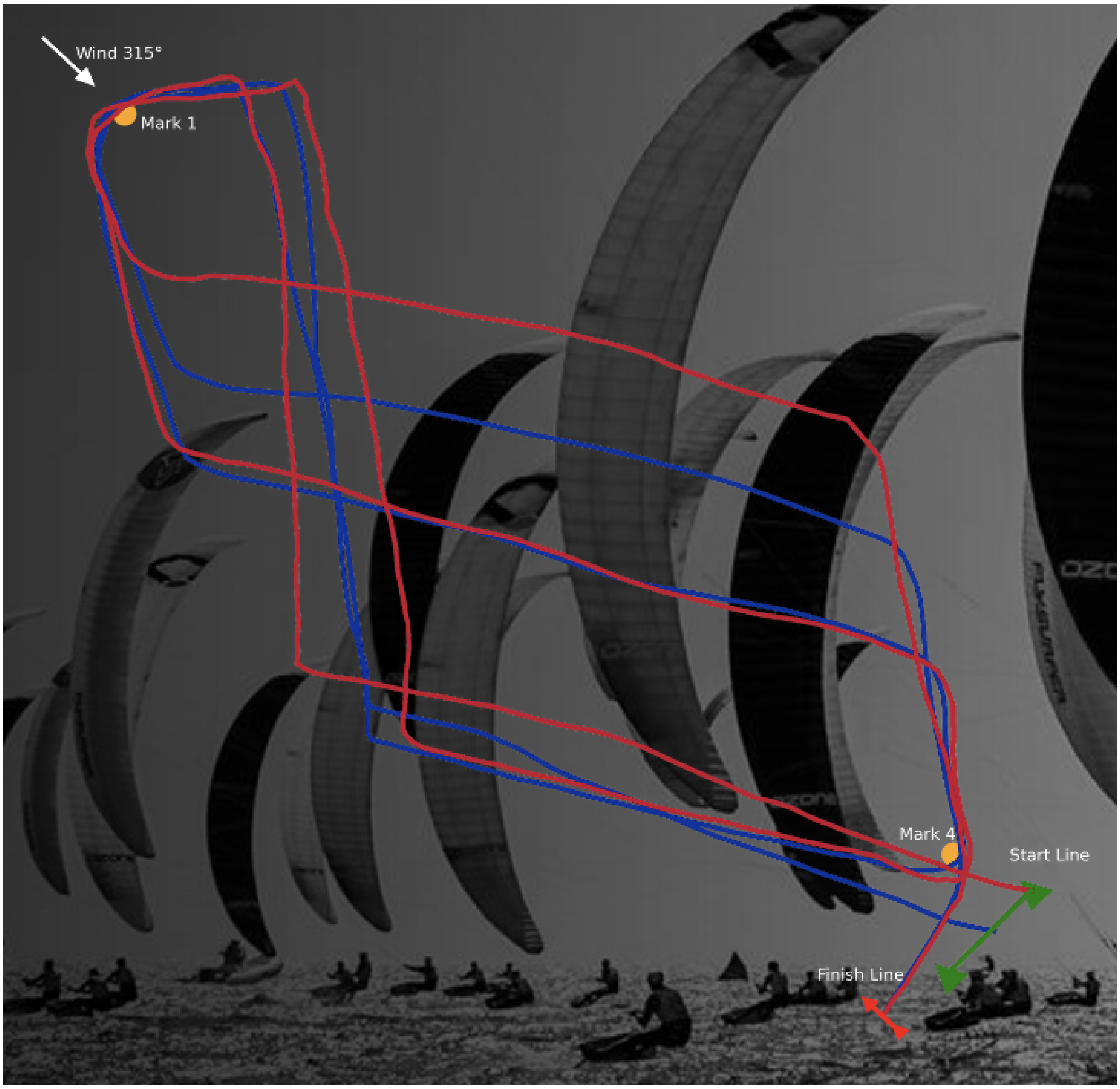

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Context and Purpose of the Performance Analysis

This report presents a detailed GPS-based analysis of the *2025 Formula Kite World Championships Final* held in Cagliari. The study focuses on the two top-performing athletes, **Riccardo Pianosi** and **Maximilian Maeder**, who concluded the event in first and second position. The main objective is to understand which technical and strategic elements shape the execution of the first upwind leg, with particular attention to both the acceleration phase during the start and the effectiveness of the tacking maneuvers. By combining GPS traces, speed profiles and derived performance metrics, the analysis provides a quantitative comparison between the two athletes, allowing us to evaluate not only how they turn but also how each maneuver influences their actual progress toward the wind.

Sailing Race Context and Technical Terminology

For readers unfamiliar with sailing, it is useful to outline the basic structure of a Formula Kite race and clarify the key terms used in this analysis. A sailing race takes place on a defined course marked by buoys, which athletes must round in a specific order. One of the most important segments is the *upwind leg*, where competitors must travel against the wind by following a zig–zag pattern.This pattern is achieved by performing **tacks**, controlled maneuvers in which the athlete turns the board through the wind to change direction.

The race begins at the **start line**, an imaginary line between two fixed points on the water. Riders approach this line from behind and must cross it precisely after the starting signal, maintaining enough speed to stay balanced on the hydrofoil while avoiding an early start. The term **Speed over Ground (SOG)** refers to the actual horizontal speed of the board across the water, while **acceleration** describes how quickly this speed increases in the moments leading up to the start.

During the upwind leg, performance is strongly influenced by **Velocity Made Good (VMG)**, which measures how much of the rider's speed is actually directed toward the upwind mark. A maneuver that is fast but poorly aligned with the wind may result in high SOG but low VMG, meaning little real progress is made toward the objective. Additional metrics such as **Distance Lost**, **Speed Drop**, **Minimum Speed**, and **Turn Radius** help quantify how efficient or costly each tack is in practice.

Understanding these concepts provides essential context for interpreting the GPS-based performance comparison between athletes, and explains why a technically impressive motion does not always translate into effective upwind progression.

About the Data

Initial Considerations About the Data

The analysis is based on raw GPS telemetry collected for two elite athletes, Riccardo Pianosi and Maximilian Maeder, during the *2025 Formula Kite World Championships* held in Cagliari. The available data consist of high-frequency GPX tracks providing timestamped geographical coordinates, which allow a detailed reconstruction of the athletes' trajectories throughout the race.

These data enable the computation of several kinematic and performance-related quantities, including Speed Over Ground (SOG), Velocity Made Good (VMG), curvature radius, distance lost during manoeuvres, and other derived metrics that are central to the evaluation of racing efficiency and tactical execution.

A major limitation of the dataset is the absence of official GPS coordinates for key racecourse elements, such as the starting committee boat, the pin end, the marks, and the finish line. Since these positions were not provided by the event organizers, they were reconstructed computationally using geometric offsets from available reference points. While this reconstruction introduces a controlled degree of spatial uncertainty, it is applied consistently across athletes and does not compromise comparative analyses.

Another methodological challenge concerns the identification of tacking manoeuvres. The GPX files do not contain embedded event markers, and automatic detection based solely on heading variations or speed thresholds proved insufficiently reliable due to GPS jitter and short-term fluctuations. For this reason, tack timestamps were manually annotated through visual inspection of trajectories, speed profiles and race simulations. In contrast, the race start time was obtained reliably from the official timing information provided in the Excel file `Formula Kite Men FINAL.xlsx`.

Despite these limitations, the dataset remains suitable for high-quality performance analysis. All transformations applied—including coordinate projection, distance computation, speed estimation, VMG calculation, curvature analysis, and normalization procedures—are fully deterministic. Given the same GPX tracks and the same manually annotated tack timestamps, the analysis can be replicated exactly.

Dataset Description

The project relies on the following datasets:

- two GPX files containing the complete GPS tracks of Pianosi and Maeder
- one Excel file, `Formula Kite Men FINAL.xlsx`, providing official race information such as wind direction and start time

These datasets represent the most complete and granular information available for analyzing real-world Formula Kite racing dynamics under competitive conditions.

Data Quality and Uncertainty Assessment

The quality of the dataset is influenced by several structural and measurement-related factors that must be explicitly acknowledged.

A first source of uncertainty arises from the spatial reconstruction of the racecourse. Since official GPS coordinates for the starting line, marks, and finish line were not available, these elements were reconstructed computationally using geometric offsets from known reference points. Although this approach introduces an approximation in the absolute positioning of racecourse features, it is internally consistent and applied identically to both athletes.

The dataset is also affected by intrinsic GPS measurement noise. High-frequency GPS recordings are subject to jitter, particularly during low-speed phases and rapid directional changes, such as tacking manoeuvres. This noise can locally influence instantaneous estimates of speed, heading, and curvature, but its impact is mitigated through window-based analyses and aggregation over time.

Another relevant aspect concerns the manual annotation of tacking events. Due to the absence of embedded event markers, the presence of GPS noise, and computational constraints that limited the applicability of more complex automatic detection algorithms, tack timestamps were identified through visual inspection. While this approach introduces a degree of subjectivity, it provides higher temporal accuracy than lightweight automated methods under the given constraints.

Finally, minor variations in sampling frequency are present in the GPX files, leading to non-uniform time intervals between consecutive GPS points. These variations were explicitly accounted for during derivative-based computations, such as speed and acceleration estimation.

Overall, these sources of uncertainty do not compromise the validity of the comparative performance analysis, as they affect both athletes symmetrically and are handled in a transparent and controlled manner.

Data Cleaning and Preprocessing

Before analysis, the raw GPS data underwent a structured and systematic cleaning process designed to ensure internal consistency and analytical reliability.

The first step consisted of temporal filtering of the GPX tracks, retaining only the GPS points corresponding to the effective race interval between the official start and finish times. This operation removed pre-start manoeuvring phases and post-finish trajectories that are not relevant to performance evaluation.

Subsequently, the data were inspected for temporal anomalies, such as duplicated timestamps or irregular time gaps. When detected, these inconsistencies were handled to preserve a coherent temporal ordering of observations and to ensure correct numerical differentiation.

Geographical coordinates expressed in latitude and longitude were then converted into a local planar coordinate system. This transformation enables the use of metric distances and angles, which are required for accurate computation of speeds, curvature radii, and geometric projections along the wind axis.

Following the coordinate conversion, the dataset was enriched with derived kinematic variables. These include Speed Over Ground (SOG), instantaneous acceleration, Velocity Made Good (VMG), and curvature radius, all computed using explicit analytical formulas and the true elapsed time between consecutive samples.

To support focused performance evaluation, specific analysis windows were extracted around key race phases. In particular, sliding temporal windows were defined around the race start and around each manually annotated tack, allowing local dynamics to be analyzed while reducing sensitivity to short-term noise.

Where required for comparative visualization, selected metrics were normalized using consistent scaling procedures applied uniformly across athletes. This ensures that observed differences reflect genuine performance characteristics rather than artefacts of measurement scale.

Methodology

Data Collection

All data were obtained from three primary sources: raw GPX files containing GPS tracks, an official Excel timing sheet, and manually annotated tack timestamps. Data extraction and parsing were performed entirely in Python using the `gpxpy` library. No web scraping or external APIs were required.

Data Processing and Transformation

Data processing was conducted entirely in Python using standard scientific libraries. The processing pipeline includes trimming the GPX tracks to the effective race interval, reconstructing the racecourse geometry through trigonometric offsets, converting geographical coordinates into a consistent planar system, and extracting analysis windows around the start and each tack.

Once cleaned, the data were transformed by merging raw coordinates with derived kinematic metrics, computing aggregated statistics at the manoeuvre level, and normalizing selected variables for comparative visualization, such as radar charts and comparative plots.

Analytical Techniques

The analysis combines descriptive statistical analysis, time-window evaluation around manoeuvres, comparative performance assessment between athletes, geometric modelling of trajectories and racecourse elements, and visual analytics through trajectory maps and speed profiles. These techniques allow quantifying efficiency losses during tacks, start performance, and the athletes' ability to maintain VMG during upwind racing.

Reproducibility

The entire processing pipeline is fully deterministic. Reproducibility is ensured because all code is provided, all computations rely on explicit analytical formulas, and no stochastic components are involved.

All figures and tables in this report are generated from the accompanying analysis notebook.

Given the same GPX files and the same annotated tack timestamps, all results can be replicated exactly.

Start Acceleration and Speed Analysis

Before evaluating the tacking phase, it is essential to analyze how both athletes approach the **start line** and how effectively they generate speed in the final seconds before the race begins. In Formula Kite racing, the start is a highly dynamic phase in which riders must simultaneously balance:

- maintaining sufficient speed to remain foiling,
- avoiding premature crossing of the start line,
- producing a controlled and well-timed acceleration immediately before the start signal.

To characterize this phase, two complementary metrics were analyzed in a temporal window spanning from -8 to $+10$ seconds around the start:

1. **Speed Over Ground (SOG)**, to assess absolute speed levels and stability;
2. **Instantaneous acceleration**, to investigate propulsion dynamics and control strategies.

Speed Over Ground (SOG) during the start phase

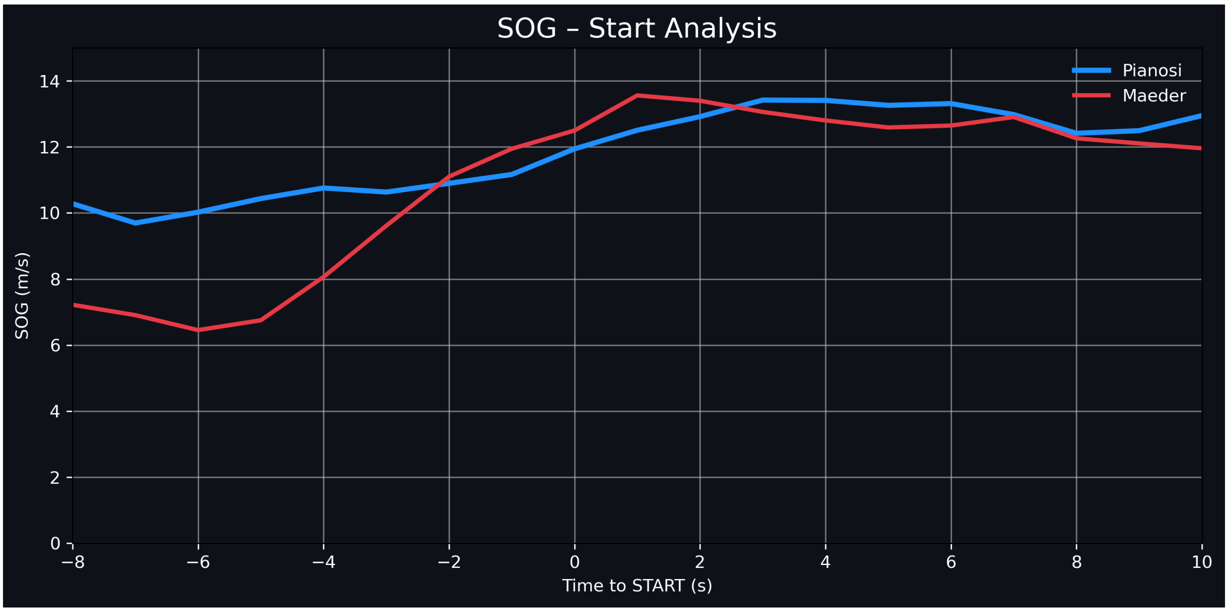

Figure 1: Speed Over Ground (SOG) profiles of Pianosi and Maeder

Figure 1 reports the SOG profiles of Pianosi and Maeder around the start line. The analysis focuses on three main aspects:

- baseline speed before the start,
- speed buildup approaching the line,
- short-term speed evolution immediately after the start.

Pre-start baseline speed and stability In the interval $t \in [-8, -3]$ s, Pianosi exhibits a consistently higher SOG, fluctuating around

$$\bar{v}_{\mathrm{P}} \approx 10\text{–}10.5 \text{ m/s},$$

with limited variability. This behavior indicates a controlled and stable pre-start trajectory, likely aimed at minimizing corrective maneuvers and preserving flow efficiency.

Conversely, Maeder starts from a substantially lower speed level,

$$\bar{v}_{\mathrm{M}} \approx 6.5\text{–}7.0 \text{ m/s},$$

suggesting a more conservative positioning or a deliberate slowdown to retain tactical flexibility before the final acceleration.

Approach to the start line Starting at approximately $t \approx -5$ s, Maeder initiates a sharp acceleration phase. This is reflected in the steep slope of the SOG curve, corresponding to a higher instantaneous acceleration

$$a(t) = \frac{d\,\mathrm{SOG}(t)}{dt}.$$

As a consequence, the speed gap progressively closes and both athletes reach nearly identical speeds at the start instant:

$$\mathrm{SOG}_{\mathrm{P}}(0) \approx \mathrm{SOG}_{\mathrm{M}}(0) \approx 12.5 \text{ m/s}.$$

This convergence highlights two different control philosophies:

- Pianosi emphasizes *speed continuity and stability*,
- Maeder emphasizes *precise speed timing through late acceleration*.

Immediate post-start dynamics In the early post-start phase ($t \in [0, 4]$ s), Maeder briefly exceeds Pianosi, reaching a peak SOG of approximately

$$\mathrm{SOG}_{\mathrm{M}}^{\max} \approx 13.5\text{–}14 \text{ m/s}.$$

This indicates that the late acceleration not only compensates for the initial speed deficit but also provides a short-term kinetic advantage immediately after the start.

Pianosi, while slightly slower in peak speed, exhibits a smoother SOG profile with reduced oscillations, suggesting rapid stabilization after crossing the line.

Acceleration dynamics during the start phase

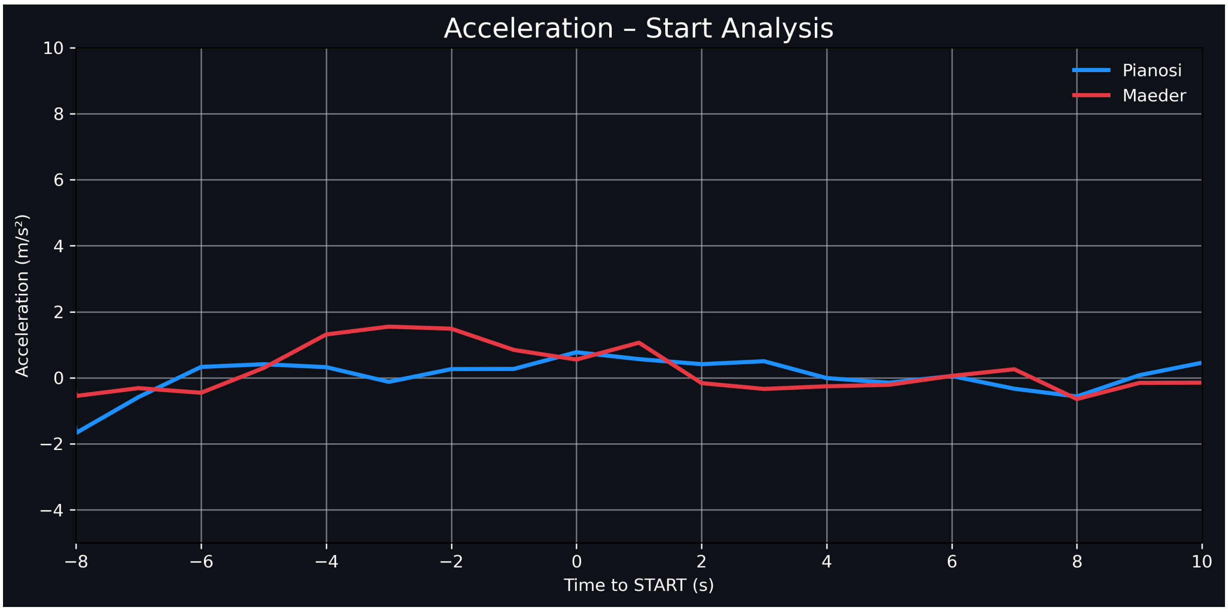

Figure 2: Instantaneous acceleration profiles of Pianosi and Maeder

Figure 2 shows the corresponding acceleration profiles. Compared to SOG, acceleration exhibits higher variability, reflecting both the noisiness of second-order derivatives of GPS data and the continuous micro-adjustments required during the start phase.

Pre-start setup phase In the early pre-start interval ($t \in [-8, -6]$ s), Pianosi displays a pronounced negative acceleration, reaching values close to

$$a_{\mathrm{P}} \approx -1.5 \text{ m/s}^2,$$

suggesting an active deceleration associated with positioning and speed regulation.

Maeder, in contrast, shows milder deceleration and acceleration values closer to zero, indicating a smoother setup phase prior to the final acceleration.

Main acceleration ramp Between approximately $t = -5$ s and $t = -2$ s, Maeder exhibits a clear and sustained acceleration ramp, peaking around

$$a_{\mathrm{M}}^{\max} \approx 1.5 \text{ m/s}^2.$$

This behavior reflects an aggressive propulsion strategy aimed at rapidly increasing speed in a short time window.

During the same interval, Pianosi maintains a more moderate acceleration profile, with values generally confined to

$$a_{\mathrm{P}} \in [0, 0.5] \text{ m/s}^2,$$

indicating a smoother and more progressive speed buildup.

Start crossing and stabilization At the start instant ($t = 0$), both athletes exhibit acceleration values close to zero, consistent with speed stabilization while crossing the line. Shortly after the start, Maeder shows a brief deceleration dip followed by a secondary acceleration peak, suggesting a corrective phase possibly related to board stabilization, sail trimming, or tactical repositioning.

Pianosi's post-start acceleration remains comparatively smoother, with smaller oscillations and a faster return to near-zero acceleration.

Synthesis Taken together, the SOG and acceleration analyses reveal two distinct start strategies:

- **Maeder** relies on late, high-intensity acceleration bursts to maximize immediate post-start speed and positioning.
- **Pianosi** adopts a more conservative and stable approach, emphasizing continuity, control, and reduced dynamic variability.

These findings show that comparable speeds at the start line can be achieved through fundamentally different dynamic processes, highlighting the importance of the entire velocity–acceleration trajectory rather than instantaneous speed alone.

Tack Performance Analysis

Following the analysis of the start phase, we now investigate the **tacking maneuvers**, which represent one of the most critical transitions in upwind sailing. In Formula Kite racing, a tack involves a complex trade-off between:

- minimizing speed loss during the board rotation,
- preserving velocity alignment with the wind direction,
- reducing the tactical distance lost during the maneuver.

To characterize tacking performance, two complementary representations were analyzed:

1. **Speed Over Ground (SOG)** time series, capturing the temporal dynamics of the maneuver;
2. **Integrated efficiency metrics**, including distance lost, VMG drop, and turn radius.

Two consecutive tacks performed by Pianosi and Maeder were examined to highlight differences in execution and efficiency.

First Tack

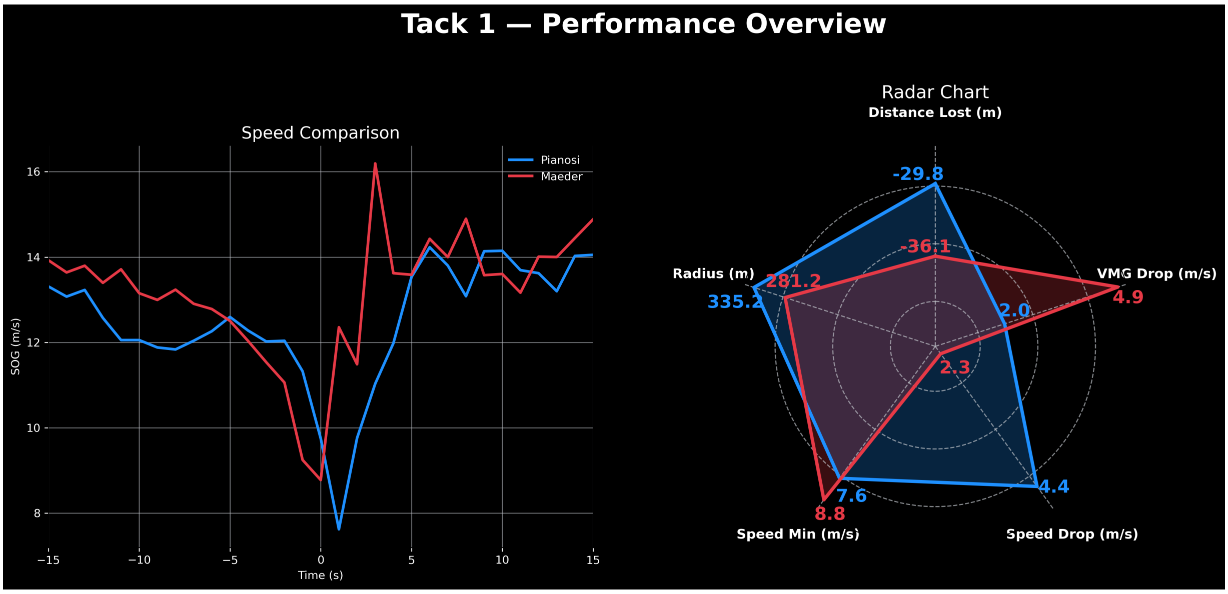

Figure 3: First tack analysis: SOG time series and efficiency metrics.

The quantitative metrics extracted from the first tack are reported in Table 1.

Metric	**Pianosi**	**Maeder**
Distance Lost (m)	29.8	36.1
VMG Drop (m/s)	2.0	4.9
Speed Drop (m/s)	4.4	2.3
Minimum Speed (m/s)	7.6	8.8
Turn Radius (m)	335.2	281.2

Table 1: Quantitative comparison during the first tack.

Speed evolution during the maneuver The SOG profile reveals distinct dynamic behaviors. Pianosi experiences a deeper speed minimum during the central phase of the tack, followed by a smooth and progressive recovery. Maeder, in contrast, maintains a higher minimum speed and shows a faster speed rebound immediately after the maneuver.

From a purely kinematic standpoint, Maeder's tack appears mechanically cleaner: the reduced speed drop and tighter turn radius suggest better instantaneous energy preservation.

Efficiency and tactical implications Despite these apparent mechanical advantages, the efficiency metrics indicate a different outcome. Pianosi loses 6.3 m less distance and experiences less than half the VMG drop compared to Maeder. This implies that Pianosi preserves a larger fraction of velocity aligned with the upwind direction throughout the maneuver.

Although Pianosi accepts a deeper temporary slowdown, his board orientation remains closer to the optimal heading. Maeder, while maintaining higher raw speed, sacrifices directional efficiency, resulting in greater tactical distance loss.

Second Tack

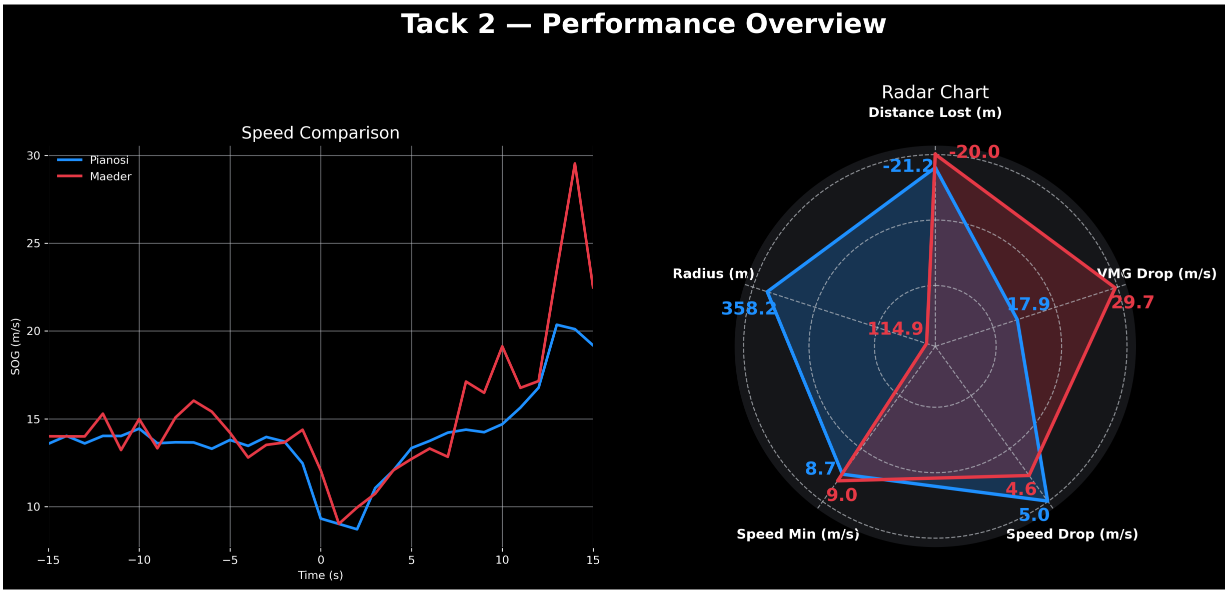

Figure 4: Second tack analysis: SOG time series and efficiency metrics.

The corresponding metrics for the second tack are summarized in Table 2.

Metric	Pianosi	Maeder
Distance Lost (m)	21.2	20.0
VMG Drop (m/s)	17.9	29.7
Speed Drop (m/s)	5.0	4.6
Minimum Speed (m/s)	8.7	9.0
Turn Radius (m)	358.2	114.9

Table 2: Quantitative comparison during the second tack.

Mechanical execution In this maneuver, Maeder executes an extremely tight-radius tack, less than one third of Pianosi's turning radius, while again maintaining a slightly higher minimum speed. From a mechanical perspective, the maneuver is highly aggressive and dynamically demanding.

Directional efficiency However, this aggressive execution comes at a substantial cost in terms of VMG. Maeder's VMG drop reaches 29.7 m/s, nearly 12 m/s higher than Pianosi's. This indicates that a large portion of Maeder's velocity during and immediately after the tack is oriented away from the upwind direction.

Pianosi, despite a wider turn and lower peak speed, preserves significantly more upwind momentum, leading to a smaller effective loss of tactical ground.

Speed Profile and VMG Relationship

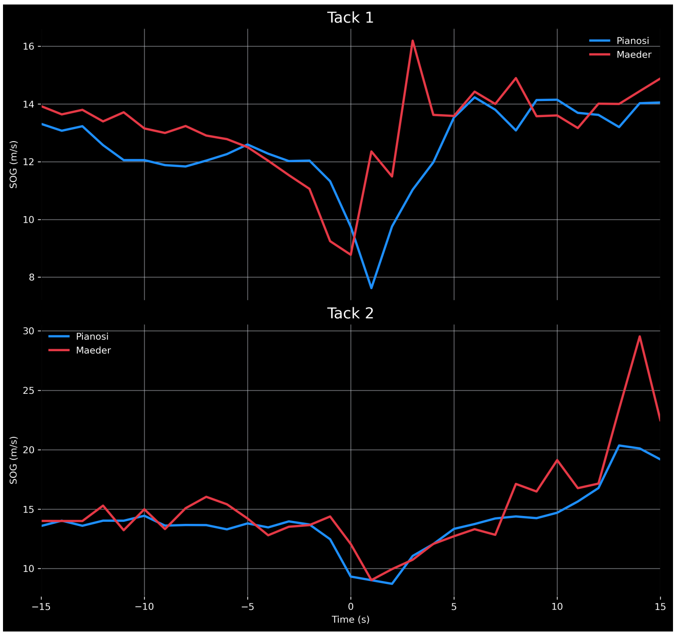

Figure 5: Speed over ground profiles for the first and second tack.

The speed profiles provide additional insight into the observed VMG behavior. Maeder exhibits pronounced post-tack speed spikes, reaching values close to 29 m/s. These peaks indicate acceleration at a relatively low heading angle, increasing raw speed but reducing the effective upwind component.

Pianosi, in contrast, shows deeper but smoother speed minima, followed by a more gradual recovery aligned with a better upwind trajectory.

The relationship between speed and VMG can be expressed as:

$$\mathrm{VMG} = |\mathbf{v}| \cos(\theta),$$

where $|\mathbf{v}|$ denotes the speed over ground and θ the angle between the velocity vector and the wind direction. An increase in $|\mathbf{v}|$ does not necessarily translate into improved VMG if accompanied by a larger heading deviation.

Synthesis

Across both analyzed tacks, Pianosi consistently converts a larger fraction of his velocity into useful progress toward the wind. Maeder's maneuvers prioritize instantaneous speed and mechanical sharpness, but at the cost of increased VMG loss.

These results demonstrate that tacking efficiency is governed not by raw speed alone, but by the ability to preserve directional alignment throughout the maneuver.

Conclusion

The combined analysis of the start phase and the upwind tacking maneuvers highlights two clearly distinct performance profiles, providing insight into the strategic differences between the two athletes.

During the start phase, Pianosi exhibits a marked advantage in baseline stability. He maintains higher and more consistent Speed Over Ground values while approaching the line, resulting in a controlled and efficient speed buildup. Maeder, by contrast, begins from a significantly lower initial speed and relies on a sharp acceleration ramp to recover. Although this explosive acceleration allows him to match—and briefly exceed—Pianosi immediately after the start, it also introduces greater variability and a higher level of mechanical risk. These contrasting approaches already anticipate the performance patterns observed later in the race.

The analysis of the tacking maneuvers further reinforces this divergence. Maeder consistently demonstrates superior mechanical sharpness, characterized by tighter turn radii, higher minimum speeds, and rapid post-tack acceleration. However, this aggressive execution comes at a substantial cost in terms of Velocity Made Good. In both analyzed tacks—particularly in the second—Maeder's heading and exit angles lead to pronounced reductions in effective upwind progress, despite high raw speeds.

Pianosi, on the other hand, consistently prioritizes efficiency over explosiveness. His tacks are smoother, his VMG losses significantly smaller, and his trajectories better aligned with the wind direction. While he accepts deeper momentary slowdowns, he converts a larger fraction of his speed into meaningful progress toward the upwind mark.

Overall, the integrated results demonstrate that, during an upwind leg, efficiency and directional control outweigh pure mechanical aggressiveness. Maeder excels in dynamic execution and acceleration, but Pianosi's stable start, measured speed management, and tactically efficient tacks yield greater effective progress. This combination of control and efficiency provides a compelling explanation for Pianosi's competitive advantage and underscores the central role of VMG preservation and trajectory optimization at the highest level of Formula Kite racing.

Data Sources

The GPS data used in this analysis were obtained from the public tracking platform `metasail.it`, specifically from the event archive available at `https://www.metasail.it/past/776/`. All tracks provided on this platform are publicly accessible and freely downloadable, enabling full reproducibility of the dataset employed in this study.

Licensing and Usage Constraints

All datasets were used exclusively for non-commercial, academic purposes. No redistribution of raw data is performed, and all computations remain internal to the project. The analysis complies with standard academic fair-use principles commonly applied to athlete-tracking and performance data.

Use of AI Tools

AI-assisted tools were used solely to support the analysis workflow, including the generation of small auxiliary code snippets, debugging and refinement of Python scripts, and improved understanding of the libraries employed. No AI techniques were used to generate, modify, or alter the data; all analytical results are entirely data-driven.