

Coaches' Insights: Safe Jump Design in Downhill Skiing

Jump design is a critical factor in athlete safety – jumps and turns are the course sections where most injuries occur, often with severe consequences due to high impact energy. Evidence demonstrates that implementing predictive jump design and subsequent adjustments **reduced severe injury rates from 8.8% per downhill day (in unassisted races) to 0%** in races accompanied by the project. This guide outlines a systematic, data-driven approach to designing safe jumps while maintaining spectator appeal.

The Core Safety Metric: Equivalent Landing Height

The primary measure for evaluating jump safety is **Equivalent Landing Height (ELH)**, which represents the impact velocity normal to the slope inclination. ELH is mainly determined by **three factors**: the take-off angle, the take-off speed, and the steepness of the landing surface.

To reduce injury frequency, jump design must avoid excessively high landing loads (high ELH) and high jump distances while remaining attractive for spectators.

Practical Design Insights

Several mechanical insights influence how a jump performs and should inform design decisions.

Take-off shape matters significantly: a linear take-off (constant inclination) results in ELH that increases nearly linearly with speed, while a concave take-off (where inclination increases 1° every 2 meters) will induce rotation during the flight phase.

Designers must also recognize that jumps can be highly **sensitive to take-off speed**; small increases in velocity can significantly escalate the ELH.

The athlete's **active take-off movement** at the point of departure significantly affects trajectory.

- An *active down motion* (a crouching or flexion movement) reduces the take-off angle and can help manage landing impact.

- Simulation data suggests that a *negative active take-off angle* (for example, -3° for a strong flexion movement) leads to lower ELH compared to a neutral (0°) or upward (positive) motion. This athlete behavior must be accounted for in design modelling.

Systematic Steps to Design a Safe Jump

Coaches and organizers can adopt a systematic approach to building and evaluating jumps.

1- Geodetic Measurement

The first step involves accurately measuring the physical profile of the jump site before construction or training begins. Use an **inclinometer** (with an accuracy of $\pm 0.1^\circ$) or a differential GPS device to measure the **take-off inclination** and the **steepness of the landing** surface.

2- Determine the Take-off Speed Range

Designers must establish the range of speeds athletes will reach at the point of departure. This information can be gathered from:

- Data from previous years' races or training sessions.
- Digitizing take-off frames from **TV footage** of previous races.
- Consultations with race directors and slope managers.
- Direct measurements using **light barriers** or video analysis during training.

3- Account for Athlete Behavior

The design must consider the range of **active up-down motion** a racer may perform at take-off, as this significantly influences the trajectory.

Model the jump using different active take-off angles: **$+1^\circ$** (slight upward motion), **0°** (neutral), or **-3°** (strong downward flexion).

4- Execute Predictive Simulations

Utilize specialized simulation software to estimate the flight trajectory and landing impact as a function of jump speed and inclination. These predictions have been proven **relatively accurate** in World Cup settings.

- **Input Data:** It combines the measured inclinations, the determined speed range, and the athlete's motion parameters.

- **Output Data:** The software calculates the **jump distance** and the **Equivalent Landing Height (ELH)**.

The simulation software is a necessary tool to prevent falls with "extremely high landing impacts" that are difficult to predict through manual observation alone.

5- Evaluate and Modify the Design

If the simulation indicates that the ELH or jump distances are too high (which are linked to serious injury), the design must be adjusted.

- **Adjust Take-off:** Modify the **take-off inclination** or the **take-off speed**.
- **Relocation:** If necessary, **relocate the jump** to a more suitable section of the terrain where the landing area provides a safer inclination and safer landing angles.
- **Shape Considerations:** Be aware that a **linear take-off** (constant inclination) leads to ELH increasing linearly with speed, while a **concave take-off** (inclination increasing by 1° every 2 meters) will induce rotation during the flight phase.

6- Validation and Continuous Monitoring

During training and competition, the jump's performance should be monitored to validate the initial design.

- **Filming:** Record athletes using video to determine actual jump distances and speeds.
- **Serial Images:** Create serial images of take-offs and landings for the furthest jumps to provide feedback to race directors after training sessions.
- **External Factors:** Measure **wind speed** as it can affect the trajectory.

Finalize with a comprehensive report including terrain profile, ELH as a function of speed, and take-off angle.

Practical Takeaways for Implementation

Predictive simulations have **proven relatively accurate in World Cup settings**, giving coaches and organizers confidence in this data-driven approach. However, important limitations must be recognized: simulations are only meaningful for balanced, symmetrical landings on both legs in an upright position.

Current models **do not account for** the risk of catching a ski edge, three-dimensional (directional) movements, or back-weighted (backward) landings, the latter being a frequent cause of ACL injuries. Despite these limitations, systematic jump design represents a proven method for dramatically reducing severe injury rates while maintaining the competitive and spectator appeal of downhill racing.