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Acceleration analysis in bobsledding – more questions than answers

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Abstract

In this analysis, speed, geometry and acceleration data from bobsled runs on 7 different tracks are evaluated. Data point clouds are obtained from 1,200 measurement runs. Some of the point clouds indicate clear trends, while others only inadequately illuminate the interrelationships in the background. However, the analyses allow the formulation of target-oriented hypotheses, which can be confirmed or refuted in the future via detailed evaluations of the data.

What was studied?

Acceleration measurements

Using a three-axis inertial sensor from Swiss-Timing, the accelerations acting longitudinally, transversely and vertically to the bobsleigh were determined in the 2015/16 season on 7 bobsleigh tracks, i.e., Altenberg, Igls, Königssee, Lake Placid, Park City, Winterberg and Whistler. In addition, distance and time, the twist in the direction of travel (roll angle) and the speed of the bobsled were measured by radar. The analyses included results from two-man and four-man bobsleighs as well as from men's and women's teams.

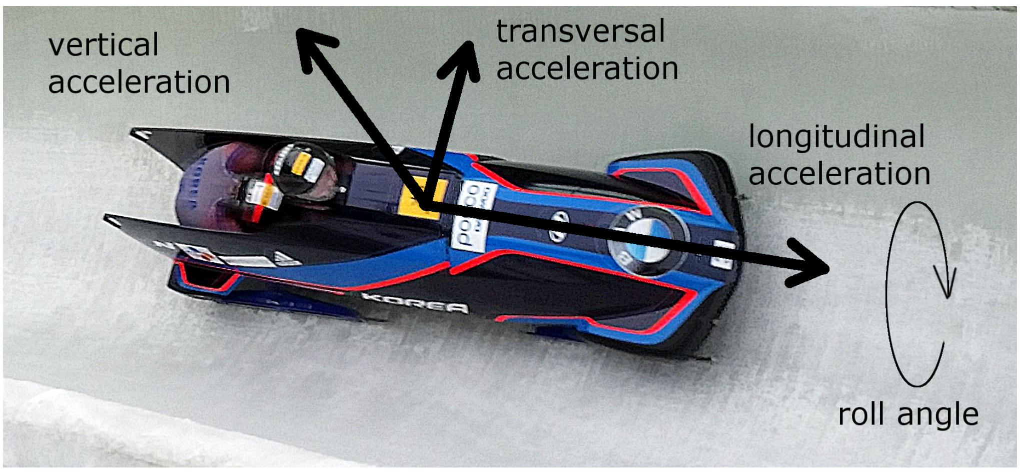

Figure 1: NInclination and accelerations in the direction of travel, transversely as well as perpendicularly. All velocities are given in km/h, accelerations in m/s^2 and angles in degrees.

Data evaluation
A total of 1,200 data sets were available for the analyses. Each data set had 6,000 lines with the above-mentioned quantities, which were recorded at 100 Hz. This resulted in a total number of analyzable data points of more than 50 million, which made manual analysis impossible. Therefore, algorithms were programmed using Python 3.8 to enable a machine analysis. In the simplest form of such evaluations, diagrams are created that show correlations. A deeper type of analysis can be done using machine learning tools, but is not shown in this paper.

Results

Gravitation and centrifugal force
Vertical acceleration acts perpendicular to transverse and longitudinal acceleration and is composed of the influences of gravity and centrifugal component. The vertical acceleration is inextricably linked to the roll angle. The roll angle is zero when the bob is stationary or traveling straight. In curves, the roll angle increases, which can reach values greater than 90°. In case the roll angle exceeds 90°, only the effect of centrifugal acceleration remains. Gravity, of course, continues to act, but has no contribution in the normal direction, i.e. perpendicular to the ice surface.

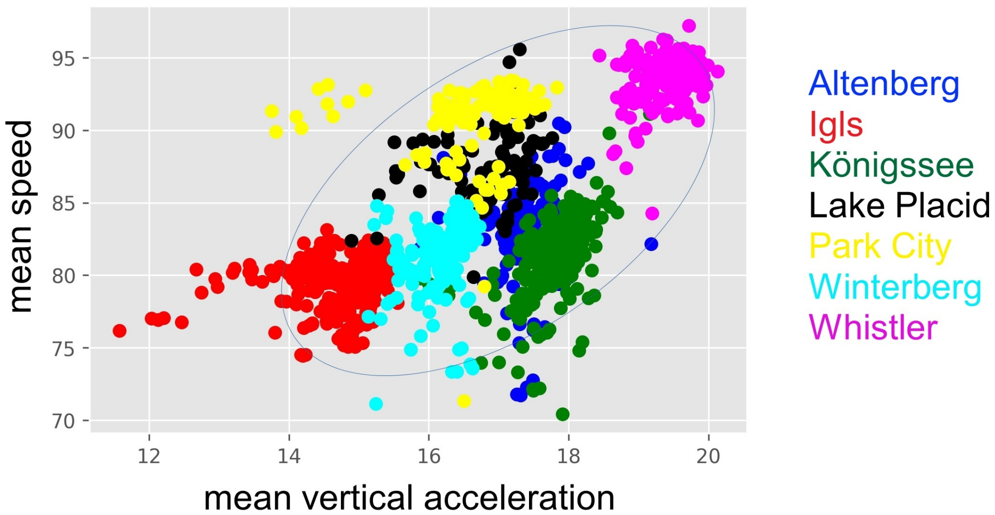

Figure 2: Data acquisition on the tracks in Altenberg, Igls, Königssee, Lake Placid, Park City, Winterberg and Whistler.

Tribologically, the force that pushes the runner into the ice is called normal force. It is valid: normal force = bob mass × (gravity + centrifugal acceleration) [1]. For the case that the roll angle is not zero, the components of the accelerations are used. Furthermore, it is true that the acting friction power density P generates heat, which melts the ice under the runner near the surface and creates a sliding film. The greater the normal force, the more friction-reducing the water film. It holds true:

$$P = \frac{\mu F_n v}{A_r} \tag{1}$$

The friction coefficient μ is not a constant here, but changes in the friction contact [2]. While v can be measured – as in this paper by radar – the contact area A_r must be calculated.

Speed and vertical acceleration
If the mean velocity (averaging over all velocity values of a run) is plotted as a function of the vertical acceleration, it becomes clear that there are fast and slower trajectories. Figure 2 shows the mean velocities achieved on the above-mentioned tracks in a band from 70 to just under 100 km/h. The top runner in terms of speeds is the track in Whistler. This runway allows speeds that are about 20 km/h above the values of the slowest track, i.e. Igls. With reference to the distribution of speeds, it is noticeable that with higher accelerations the speeds increase. When clustering the speeds, there are tracks – such as Whistler – that have a low dispersion, while the Park City track disperses

over a wide range. The situation is similar for the tracks at Königssee in comparison with Igls. In the distribution of speeds, Whistler again stands out with a small range of variation of about 7 km/h. In Altenberg, on the other hand, the speeds vary in a range of almost 20 km/h. This diagram represents a kind of stress test for the pilots. For Whistler there are acceleration values greater than 4g from curve 2 and speeds of over above 130 km/h for all further curves. The points are close to each other, so the bobsleighs run for a long time in the in the range of the average speed for a long time. Igls is slower overall, the curve radii are often large, and the measurement points are distributed more widely. The mean value of all points should thus be an indicator for the difficulty of the track [3].

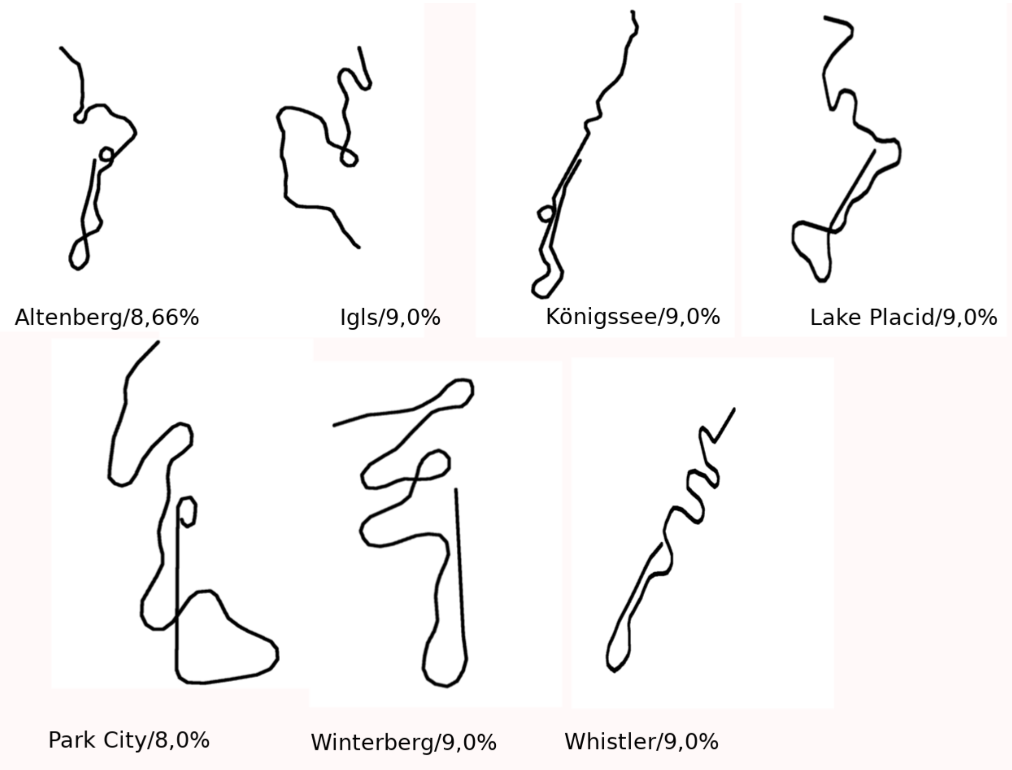

Figure 3: Trajectories considered and average slope.

Speed and lateral acceleration

The lateral accelerations are the result of the steering intervention. If the bobsled were to run freely, there would be no lateral acceleration, but dangerous crashes. The tracks are also designed in such a way that the optimum line can only be found with steering intervention. Sometimes there are several driving lines that lead to high speeds.

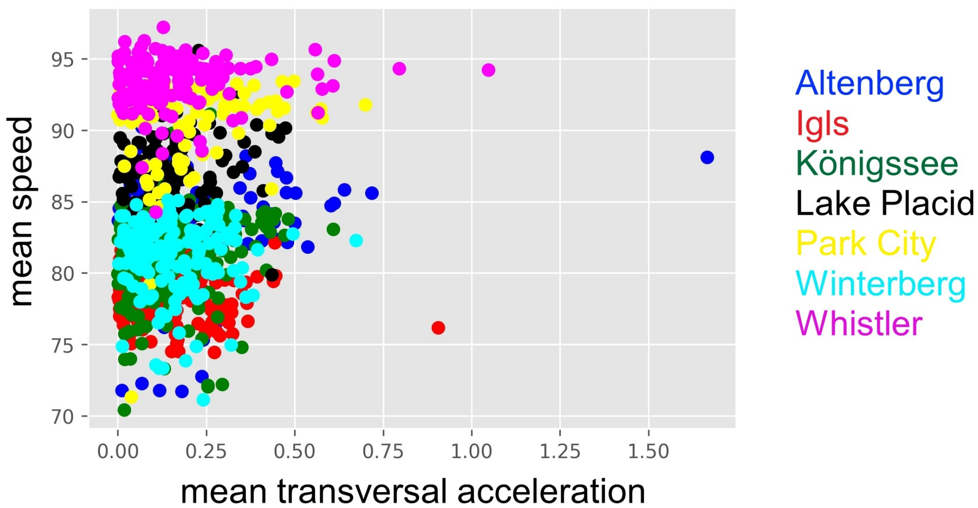

Figure 4: Speed as a function of accelerations transverse to the direction of travel of the bob.

Thus, the magnitude of the lateral accelerations should be related to the velocity. Figure 4 represents this dependence. Since by definition there are positive or negative transverse accelerations due to the position of the curves (to the right or to the left), all values were presented as magnitude. For all tracks, there is a slight tendency towards the upper right, i.e. towards higher speeds. For the Altenberg track, there is an extreme value for one run. This could have been caused by the entrance to curve 13, where there is an entrance clothoid of only 3.5 m. The transition from a curve radius of 25 m to 3.5 m generates a transverse jerk [3]. Despite the many data points, however, the dependence remains fuzzy, suggesting that other effects – possibly driving error – must have an influence.

Speed and longitudinal acceleration
If the mean velocities are put in relation to the longitudinal acceleration, it becomes clear that almost all accelerations have negative values. This means that apart from the start, the bob is braked throughout the entire run. Similar to the lateral acceleration, the values spread out slightly with increasing speed. Between 70 and 75 km/h the spread is about 0.5 m/s^2 and at 90 km/h it is about 2 m/s^2. After the takeoff process, the longitudinal acceleration is the direct result of vertical and lateral acceleration.

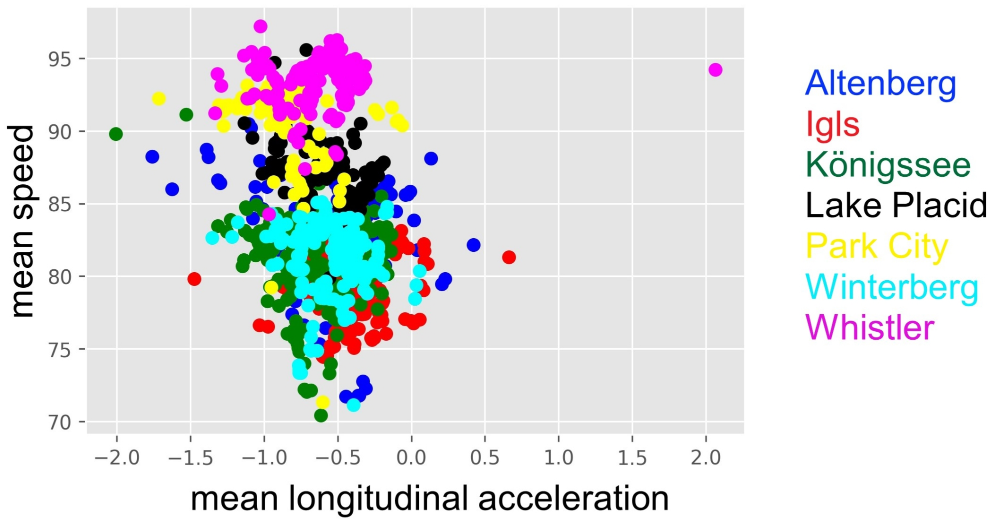

Figure 5: Speed as a function of accelerations along the direction of travel of the bob.

Discussion

Based on the observation of the point clouds, a whole series of hypotheses can be made.

- The dispersion of the vertical accelerations depends on the intersection of the trajectory as well as on the presence of several equal driving lines.
- The dispersion of velocities is due to driving errors.
- The larger the vertical accelerations are, the smaller is the influence of the material.
- The scatter of velocities can be influenced by ice temperature [4] as well as the preparation condition of the runners [5,6].

It becomes clear that answers to the posed questions cannot be derived from the presented diagrams alone. Presumably, the answers lie in the detailed evaluation of the individual trajectories, taking into account the curve situations at hand. It may be necessary to include the analysis of videos.

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About Author

Matthias Scherge is a professor of tribology. This is the science of friction, wear and lubrication. Prof. Scherge heads the Fraunhofer MikroTribologie Centrum, teaches at the Karlsruhe Institute of Technology and manages Team Snowstorm. He also advises the Nordic Paraski Team Germany and several national and international athletes on scientific and technical issues.

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