AN APPROXIMATE SIMULATION MODEL FOR INITIAL LUGE TRACK DESIGN

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Purpose: The purpose of this study was to develop an approximate simulation model for luge to support the initial design of new artificial ice tracks.

Introduction

Bobsled, luge, and skeleton are considerably fast winter sports. For example, at the Whistler Sliding Centre a speed of 151 km/h and a normal acceleration of 5.2g were measured in luge. Because of safety issues FIL and/or FIBT request for new artificial ice tracks a maximum speed below 135 km/h and a centrifugal force below 5g. Thus, the purpose of this work was to develop an approximate simulation model to predict these variables.

Methods

The Whistler ice track (track length 1379 m, drop height 153 m, 16 turns, turn radii 12-100 m) was chosen to test the method. The track surface is composed of straights and turns. Its geometry is given by the construction plan. In straights the cross section is a horizontal line and in turns the cross section is modeled as a quarter ellipse approximating the Lillehammer track's surface.

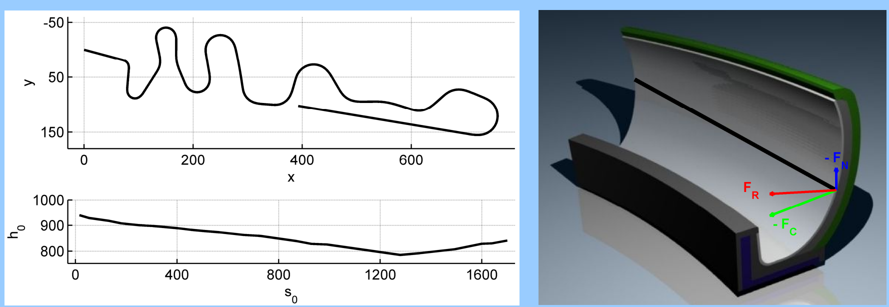

Figure 1: Top and side view of the Whistler ice track (left). 3d model of a turn section with the forces acting perpendicular to motion of the luge.

The 1d equation of motion for a point mass is formulated along the trajectory of the luge. Forces considered are weight $F_W=mg$, drag $F_D=½\rho C_d A v^2$, surface reaction force F_R, and friction $F_F=\mu F_R$. The luge is accelerated by the projection of the weight on the trajectory $F_P=mg\cdot\sin\alpha$. In straights the surface reaction force is given by $F_R=F_N$ with $F_N=mg\cdot\cos\alpha$. In turns the surface reaction force is given by the combination of F_N and the centrifugal force $F_C=mv^2/r$. The equation of motion along the assumed path is given by $md^2s/dt^2=F_P-F_D-F_F$, leaving the problem of defining the location of the trajectory within the cross section. In straights the trajectory is in the middle of the plane track surface. In turns we assume that no transverse forces act on the luge. Consequently, the surface reaction force F_R is normal to the track surface. This determines the position of the luge in the cross section. The solution of the equation of motion is computed iteratively. In each iteration the actual turn radius r is taken from the prior iteration. This process is iterated until the change of the trajectory between consecutive iterations becomes negligible. The parameters C_dA, and μ are determined using a weighted least squares approach. All calculations are performed in Matlab. Details of the methods are given in [1].

To validate the simulation model the computed normal acceleration of the luge $a_n=F_R/m$ is compared to measured data of runs of an official training at Whistler. The normal acceleration is measured using an accelerometer of Analog devices during the entire run. The raw data are filtered using a low pass Butterworth filter with a cut-off frequency of 2 Hz.

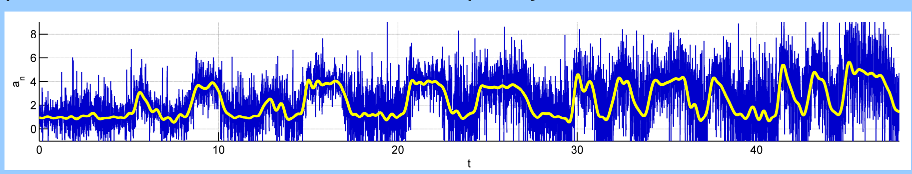

Figure 2: Normal acceleration a_n [g] versus run-time t [s] in single luge at the Whistler ice track. The noisy signal is the recorded signal (blue) and the smooth line the filtered signal (yellow).

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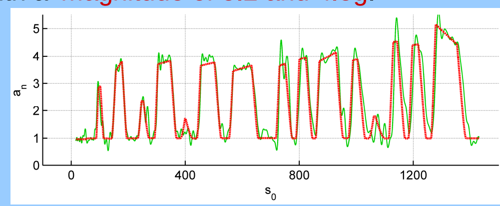
Reference: **[1]** Mössner, M, et al (2011) J Biomech **44**, 892-896.

Results

We calculated runs with exact overall run-time. In single and double luge the drag area was 0.047 and 0.064 m^2 and the coefficient of friction was 0.010 and 0.012. The speed increased almost linearly and the maximum of 41.9 and 39.1 m/s in single and double luge was achieved at the entrance of the last 180° turn. The recorded acceleration normal to the ice surface in single luge was very noisy with peak values of 11g and a r.m.s. deviation between the filtered and the raw signal of 1.0g. For both single and double luge the filtered normal acceleration of the measurement compared well to the normal acceleration obtained in the simulation. The maximum acceleration occurred for both cases at the entrance of the last 180° turn with a magnitude of 5.2 and 4.5g.

Figure 3: Simulated (red) and measured (green) normal acceleration a_n [g] versus distance along the baseline s_0 [m] at the Whistler ice track.



The effect of model parameters was assessed by varying the input data of the run in single luge. The variation of the drag area between 0.044-0.050 m^2 and the coefficient of friction between 0.008-0.012, as well as the reduction of the mass from 117 to 107 kg caused a variation of the maximum normal acceleration below 0.25g. The variation of the vertical drop of the ice track by 14 m caused a change in maximum normal acceleration of 0.46g. The reduction of all turn radii by 10% caused an increase of the maximum normal acceleration by 0.44g. For the speed similar effects were observed.

Discussion

Running safety is one of the main concerns when designing a new track. High accelerations and a large amount of vibrations are reported by coaches to be the origin of driving faults and thus are accident prone. Any speed reduction considerably reduces the impact energy in accidents and therefore efficiently increases safety. So, maximum speed and normal acceleration were used as a measure for running safety.

Run-time, speed, and acceleration were simulated for a competitive run in single and double luge at the Whistler Sliding Centre. Since the simulation model accurately predicted the speed and the acceleration of the luge, the model is adequate to initially evaluate the safety of proposed layouts of new luge tracks. Parameter studies show that changes in drag area, coefficient of friction, or luge mass were of minor importance as long as variations relevant for elite luge were considered. Moderate changes in the vertical drop or the turn radii caused significant changes in the maximum speed and normal acceleration. In early planning stages of new tracks turn radii and vertical drop are adapted to a given terrain. For the detailed specification of the course a simulation model has to be applied. In the design phase, speed can most effectively be restricted by choosing a smaller vertical drop and normal acceleration by a larger turn radius. Thus, running safety can effectively be influenced in the planning phase. The presented model was used to predict the driving dynamics of two recently designed but not yet built luge tracks in Bludenz, AT and Schliersee, DE.

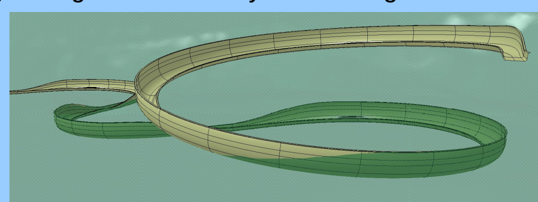


Figure 4: A sample for a track in the design phase.

At one of the world's fastest ice tracks a maximum speed of 41.9 m/s and a normal acceleration of 5.2g were measured and simulated. These accelerations are slightly above the limit of the rules of the FIBT (5g at all). Furthermore, due to the hardness of ice and the roughness of the ice surface, the measured normal acceleration was highly oscillating with peak values of 11g and a r.m.s. deviation to the filtered acceleration of 1.0g. In conclusion the combination of the high mean acceleration with the significant amount of vibration during runs at Whistler may cause a significant accident risk.