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AN APPROXIMATE SIMULATION MODEL FOR INITIAL LUGE TRACK DESIGN

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SUMMARY

The purpose of this study was to develop an approximate simulation model for luge to support the initial design of new ice tracks. The trajectory of the luge on the ice track was estimated using a quasi-static force balance and a 1d equation of motion was solved along that trajectory. The drag area and the coefficient of friction were determined by parameter identification using split times of the Whistler Olympic ice track. The values obtained agreed with published values. To validate the ability of the model to predict speed and accelerations normal to the track surface, a luge was equipped with an accelerometer to record the normal acceleration during the entire run. Simulated and measured normal accelerations agreed well. In a parameter study the vertical drop and the turn radii turned out to be the main variables that determine speed and acceleration. Thus the safety of a new ice track is mainly ensured in the planning phase, in which the use of a simulation model is essential.

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. For new and as yet undesigned tracks one needs an estimate of speed and normal acceleration acting on the luge with the athlete. Thus, the purpose of this work was to develop an approximate simulation model to predict these variables.

METHODS

In this section a brief outline of the methods are given, for full details we refer to [1]. 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 and is given by the baseline, which follows the bottom of the track, and the cross section. The data for the track geometry are 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.

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 approximately given by the norm of the vector sum of F_N and the centrifugal force $F_C=mv^2/r$, hence, $F_R=(F_N^2+F_C^2)^{½}$. The equation of motion along the assumed path is given by $md^2s/dt^2=F_P\text{-}F_D\text{-}F_F$, 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 the first iteration we assume the luge to move along the baseline. We integrate the equation of motion along that trajectory. As result we obtain the motion of the luge along the chosen trajectory and the forces acting on the luge. Given the reaction force F_R, a better guess for the location of the trajectory is computed. This process is iterated until the change of the trajectory between consecutive iterations becomes negligible. Finally, the parameters C_dA, and μ are determined using a weighted least squares approach. All calculations are performed in Matlab (The Mathworks, Inc, Natick, MA, US).

To validate the simulation model the computed normal acceleration of the luge $a_n = F_R/m$ is compared to measured data. Two runs of an official training at Whistler are analyzed. For the measurement an accelerometer (ADXL321, range ±18g, Analog Devices, Inc, Norwood, MA, US) is mounted below the seat of the luge, to record the normal acceleration during the entire run. The acceleration data are filtered using a low pass Butterworth filter with a cut-off frequency of 2 Hz.

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 (Fig. 1). For both single and double luge the filtered normal acceleration of the measurement compared well to the normal acceleration obtained in the simulation (Fig. 2). The maximum acceleration occurred for both cases at the entrance of the last 180° turn with a magnitude of 5.2 and 4.5g.

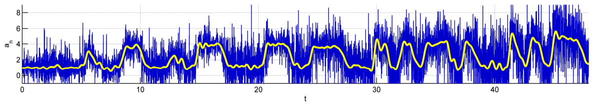

Figure 1: Normal acceleration a_n [g] versus run-time t [s] in single luge at the Whistler ice track. The noisy signal is the recorded signal and the smooth line the filtered signal.

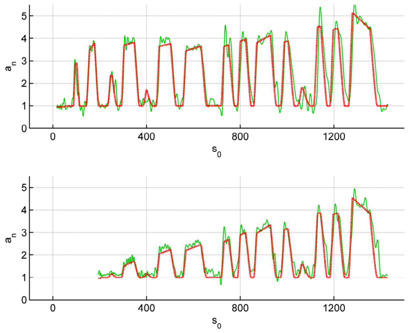

Figure 2: Simulated (dashed line) and measured (solid line) normal acceleration a_n [g] versus distance along the baseline s_0 [m] at the Whistler ice track. Shown are a run in single (top) and double luge (bottom).

In a final step 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.

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. The EU-directive on minimum health and safety requirements for whole body vibrations at work places applied requires a r.m.s. value below 2.0g for a duration of 100 s. In conclusion the combination of the high mean acceleration with the significant amount of vibration during runs at the Whistler ice track may cause a significant accident risk.

The model was validated by comparing the measured normal acceleration of two runs in elite luge with the simulated normal acceleration. The drag area and coefficient of friction were determined by parameter identification for each simulated run separately and the values obtained are in reasonable agreement with published data. To simplify the 3d equation of motion, the trajectory of the luge on the ice track was estimated. Consequently, the equation of motion was formulated as a 1d equation and solved along that trajectory. We assumed that the luge was in equilibrium with respect to the transverse components of weight and centrifugal force. No shearing force was considered, either from the orientation of the luge with respect to the running direction or from the athlete's steering movements. For the simulation of such aspects a 3d model is required. In this work variables like drop height and turn radii and, consequently, speed and normal acceleration turned out to be the basic variables. The presented model is not capable to analyze human factors like proper steering. However, the given approximate simulation model is appropriate for an initial safety assessment of proposed new tracks and, as the case study of Whistler shows, the method can also be used to reevaluate existing tracks.

ACKNOWLEDGEMENTS

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REFERENCES

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