Simulation of Speed and Normal Acceleration in Luge

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Introduction

in luge high speeds and normal accelerations occur
e.g.: Olympic track at the Whistler Sliding Centre

- for safety reasons speed and load must be restricted.
- luge track construction is very expensive.
- for planning new luge tracks one needs detailed information on the expected speed and acceleration of the luger.

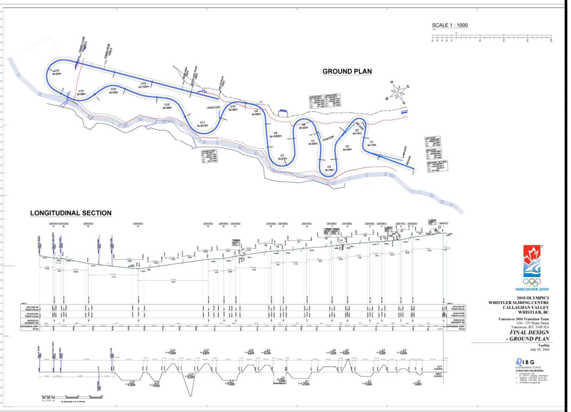
purpose: development of a simulation tool to predict speed and normal acceleration of a luger in the track.

Method

geometry of the track at the **Whistler Sliding Centre**

track length 1450 m
vertical drop 152 m
16 turns
mean slope 11%

distance along base-line
altitude, slope angle,
and turn radius



Method

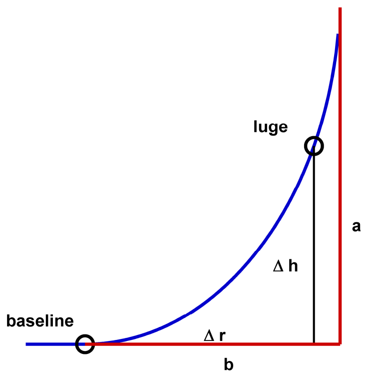
propulsive weight	$F_{WP} = mg \sin \alpha$	
normal weight	$F_{WN} = mg \cos \alpha$	
drag	$F_D = ½ \rho C_D A v^2$	
centrifugal force	$F_C = m v^2 / r$	
normal reaction force	$F_R = F_{WN}$	in straights
	$F_R = (F_{WN}^2 + F_C^2)^{½}$	in turns
friction force	$F_F = \mu F_R$	
equation of motion	$\mathbf{m\,a = F_{WP} - F_D - F_F}$	

Method

track cross section

in straights flat
in turns elliptical
major/minor axis a/b = 1.78/1.29 m

base line
$r = r_0$, $h = h_0$
luge, real position of trajectory
$r = r_0 + \Delta r$, $h = h_0 + \Delta h$



Method

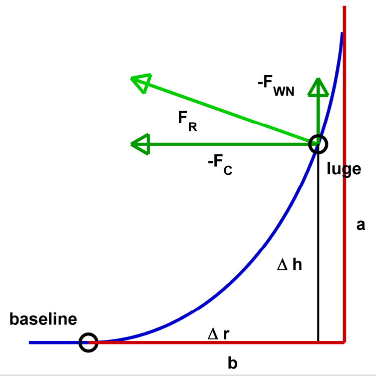
position of the luge in the track

reaction force F_R normal to the track surface
→ nonlinear equation for Δr

$$\frac{a}{b}\frac{\Delta r}{\sqrt{b^2-\Delta r^2}} = \frac{v^2}{(r_0+\Delta r)g\cos\alpha}$$

→ Δh from ellipse equation

$$\left(\frac{\Delta r}{b}\right)^2 + \left(\frac{a-\Delta h}{a}\right)^2 = 1$$



Method

integrate differential equation, but

restrict integration step size to $\Delta s = 0.04$m
in each step compute the position in the track, i.e.
compute Δr, Δh using r and v from the previous step

parameter identification

select initial velocity v_0, drag area $C_D A$, and friction coefficient μ subject to 5 run-times in an official training

Validation Data

acceleration measurement
sensor ADXL321
Analog Devices Inc, Norwood. US-MA

range: ±18g

accelerations were filtered
Butterworth filter
in forward and backward direction
cut-off frequency 2 Hz

Results

movement of the luge in the track (s, v, a, F..)

mean friction coefficent $\mu = 0.0142$

Itagaki et al. (1987) for a sled runner on ice

$\mu = 0.006\text{-}0.014$

mean drag area $C_DA = 0.050\ m^2$

wind tunnel measurements of the Austrian Luge Federation

$C_DA = 0.044\text{-}0.060\ m^2$

Results

run times

overall run-time exact due to the parameter identification

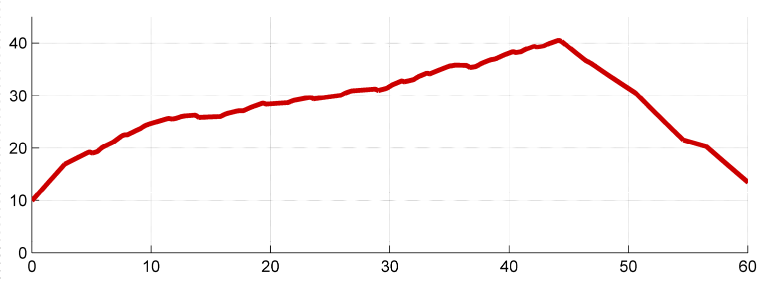
difference in transient times at the 5 measurement points

0.44, -0.35, -0.46, -0.19, and 0.00 s

in the simulation the luge moves slower at the start and faster after the first interim time

Results

speed of the luge

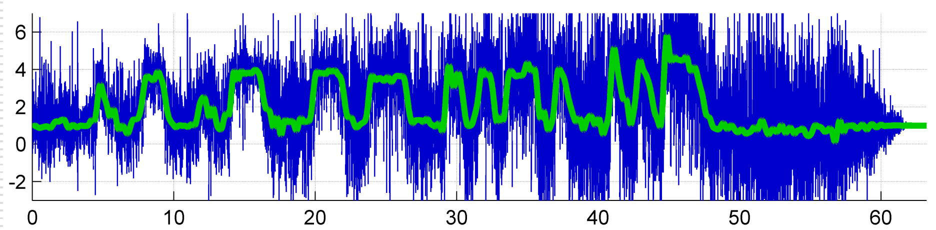


speed v [m/s] vs. run-time t [s]

speed at entry of 180° turn:	40.5 m/s	simulation
	40.7 m/s	measurement

Results

acceleration measurement

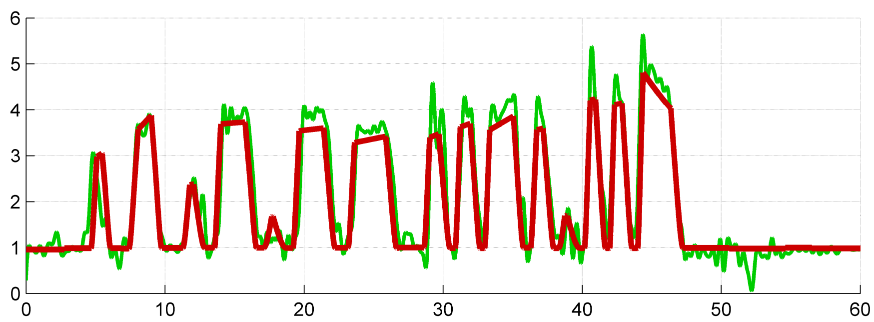


normal acceleration a [g] vs. run-time t [s]

unfiltered data (blue) filtered data, Butterworth, 2 Hz (green)

Results

simulated vs. measured normal acceleration



normal acceleration a [g] vs. run-time t [s]

measured and filtered data (green) simulated data (red)

Discussion / Conclusions

main result:

speed and normal acceleration were successfully simulated for a run in the track of the Whistler Sliding Centre.

measured and simulated data agree very well

- normal acceleration
- velocity at entrance to 180° turn
- total running time
- computed mean drag area
- computed mean friction coefficient

Discussion / Conclusions

differences between measurement and simulation

runtimes for transient times differ (total runtime agrees)

reasons might be

- acceleration pushes of the luger in the first section
- changes of ice friction along the track
- different friction coefficients for straights and turns
- changes of drag area due to movements of the luger
- luge shearing is not implemented
- transversal accelerations are up to 1g
- steering movements of the luger are not modeled

Discussion / Conclusions

benefits of the simulation model

- the model is very simple but accurate
- main influence factors for speed and normal acceleration are
    + the vertical drop or the mean slope angle
    + the turn radius

so, the simulation tool is well suited to design new tracks !

Discussion / Conclusions

if runtimes are provided, the overall runtime is very sensitive to changes in mean drag area as well as mean friction coefficient

therefore, tool can be used to calculate drag area and friction coefficients for luging in competitive environments

Thank you for your attention

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