Scientific approach to ski safety

SIR — During the 1994 Ski Flying World Championships in Planica, Slovenia, athletes performed jumps of more than 200 m for the first time, the present record being 209 m. Despite the fact that millions of spectators witnessed these jumps, distances of more than 191 m have been ignored by the International Ski Federation (FIS) in an attempt to reduce the jump lengths; this procedure obviously does not reduce the hazards of this dangerous sport. Scientific studies are urgently needed to provide a reliable basis on which safety enhancement strategies can be based.

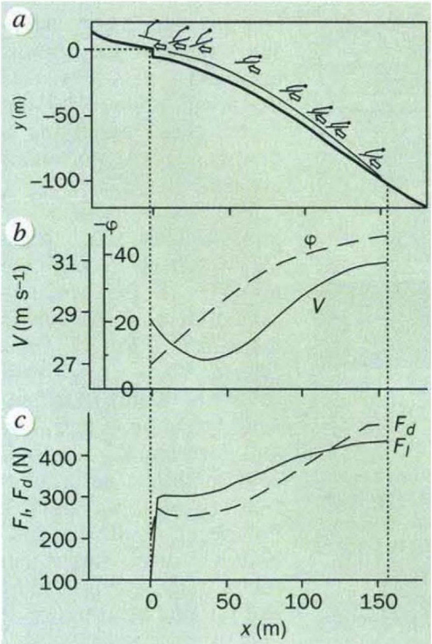
We have performed wind-tunnel measurements with world class athletes in various flight positions, undertaken field measurements during the world championships in ski flying 1994, and have mapped ski jumping to a computable simulation model. Our results explain the effects of equipment, flight style changes, the reason for the high tumbling risk and sensitivity to gusts observed. This information is of use for making changes to the FIS regulations.

We measured the high torque of the skis in the airstream and the FIS followed our suggestion to limit the percentage of front ski to total ski length before the 1994–95 winter (to 57%). As a consequence the pitching moment balance has been eased and only one tumbling accident occurred during the 1994–95 World Cup, compared with 10 in 1993–94. Another urgent problem is the anorexia deliberately induced by the athletes (low weight increases the jump length). We suggest a regulation relating ski length to body weight (a self-regulating approach).

Simulations can predict the trajectory during the flight phase and investigate the effects of parameter and initial value variations[1–4]. We developed a highly reliable mapping of ski jumping to a computable simulation model, which contains the dependencies of the lift and drag forces to the flight position. A representative set of data, obtained with the 1994–95 World Cup winner (who was the first to fly more than 200 m) in a 5 x 5 m^2 wind tunnel, was used to determine a reference jump. The values for the lift area L and the drag area D from the series of wind tunnel measurements were chosen according to the mean position angles measured for 15 excellent jumps during the world championships in ski flying, Planica, Slovenia, 1994.

L and D values have increased markedly during the past two decades[5] due to changes in equipment and flight style. L and D measured with the holder of the world record in 1976 using his old equipment and flight style were less than 60% of the results obtained with athletes of today.

The figure (a) shows the profile of the jumping hill in Planica and the trajectory $y = y(x)$ of this reference jump. The approach velocity v_0 was set to 28.6 m s^{-1} (mean of the officially measured values). The jump length of l = 186.7 m to be obtained (mean jump length from the field) was found at a take-off velocity component due to the athlete's jumping force (perpendicular to the ramp) of v_{po} = 2.24 m s^{-1}. The flight path deviates remarkably from the parabolic trajectory. The actual angle of the tangent to the path $\varphi = \varphi(x)$, and the velocity $v = v(x)$ are shown in b. The plot in c of the lift force F_l (acting perpendicularly to the actual tangent to the path) and the drag force F_d shows that the velocity component perpendicular to the hill at landing (4.18 m s^{-1}) corresponds to that of a jump onto a horizontal plane from h_l = 0.89 m height (equivalent landing height).



Results with the reference jump. *a*, Profile of the jumping hill in Planica and the trajectory $y(x)$, with the flight position angles found in the field (means of 15 jumps) sketched above. *b*, Velocity $v(x)$ and angle of the flight path $\varphi(x)$. *c*, Lift force F_l and drag force F_d. L and D values used for this reference jump (in m^2): 0.2 and 0.4 (at t = 0 s), 0.65 and 0.60 (0.2 s), 0.68 and 0.58 (0.4 s), 0.77 and 0.64 (2.3 s), 0.79 and 0.73 (4.0s), 0.78 and 0.79 (5.0 s) and 0.79 and 0.86 from 6.0 s onwards. Linear interpolation was used between. The air density was 1.15 kg m^{-3}; the mass m of the athlete with equipment was 70 kg.

How do the initial values and parameters influence the flight? We kept L and D values constant from t = 5 s onwards in the following simulation. The jump length l obtained this way is 186.6 m, the flight time t_l = 6.59 s, the landing velocity v_l = 31.4 m s^{-1}, and the equivalent landing height h_l = 0.89 m (at v_0 = 28.6 m s^{-1}, v_{po} = 2.24 m s^{-1}, m = 70 kg). Starting out from this simulation, an increase of v_{po} to 3.0 m s^{-1} (variation A), corresponding to an excellent take-off jump of the athlete[4], increases the jump length to 195 m (t_l = 6.92 s, v_l = 31.52 m, h_l = 1.59 m). The same jump length can be obtained using an approach velocity v_0 of 28.98 m s^{-1} (B). A wind blowing up the hill (130°, measured from a horizontal line) with a constant speed of 1.4 m s^{-1} also results in l = 195 m (C). We also considered variations of the L and D values in functions corresponding to different flight styles, athletes or equipment. Increasing all L and D values in these functions by 11% (case D) or just L by 2.3% (E) also leads to a 195-m jump. A reduction of the mass (athlete with equipment) to 63 kg also results in l = 195 m (F). Finally, a shallow ramp angle of –9.7° (compared with –11.6°) yields l = 195 m again (G). In simulations C, D, E and F the equivalent landing height is reduced to 1.37 m, compared with A (1.59), B (1.49) or G (1.62 m).

In the real world, the change of one parameter will influence the others; athletes have to solve extremely difficult optimization problems in real time. The longest jump performed so far led to 209 m, which results from a simulation using v_0 = 28.44 m s^{-1} (measured in the field), v_{po} = 3.0 m s^{-1} (assumption of an excellent take-off jump)[4], and L increased by 5.6%. This increase in L is realistically imaginable for this world-record jump. The landing velocity obtained is 31.44 m s^{-1} and h_l = 2.43 m. Using an appropriate parameter protocol to simulate the 196-m jump from 1995 at the Oberstdorf jumping hill results in h_l = 2.62 m. The athlete could not stand this jump in the competition.

Wolfram Müller
Dieter Platzer
Bernhard Schmölzer
Institut für Medizinische Physik und Biophysik,
Harrachgasse 21,
8010 Graz, Austria

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