WIND TUNNEL MEASUREMENTS IN SKI JUMPERS AND SIMULATION OF THE JUMPS - THUNDER BAY, HILL K 90

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INTRODUCTION

The flight distance in ski jumping depends on the tangential and normal velocity components at release phase, jumper's posture in the air, the change of his orientation and wind. The tangential and normal velocity components at release phase depends on starting gate level, friction between skis and track, gliding position and takeoff movement on the takeoff platform. The posture changes during flight mean changes in the polar (lift coefficient vs. drag coefficient) of the flying body. Using simulation it is possible to evaluate the meaning of different factors in the total ski jump model (Tani & Iuchi, 1971; Remizov, 1984 and Hubbard et al., 1989) and to compare results to the real performance. Six high calibre ski jumpers were selected for the simulation analysis at Lillehammer World Cup competition 1993. The total mass of the jumper-equipment system, the average of the official in-run velocity, the release velocity perpendicular to the takeoff table measured from the video analysis and wind velocity were used for simulation input data. The average measured distance in the respective competition was 110.4 ± 3.7 m and the simulated distance 107.3 ± 6.7 m, respectively (Luhtanen et al., 1995a).

The purpose of this presentation is to introduce contents of input variables (for gliding, takeoff, flight and landing phases) of a modified Aquila simulation program for the center of gravity of jumper-equipment system and to apply the input data for the K 90 m of Thunder Bay. The program was developed on the basis of wind tunnel measurements in ski jumpers. The simulation program took into account all external conditions influencing on the lengths of the jumps. The program was developed to work in Excel with its function macro programming.

METHODOLOGY

Nine volunteered high calibre Finnish ski jumpers (height (h) = 175 ± 6 cm, mass (m) = 62.4 ± 6.1 kg, ski length (l_s)= 255 ± 6 cm with 55 % frontal binding location and mass of the equipment in total: skis, helmet, shoes and official competition clothing (m,) = 14.9 ± 1.3 kg) served as subjects in a subsonic Gttingen type closed circle wind tunnel m and cross section of 3.68 m^2 in the test area (Luhtanen et al., 1995b). The frontal binding location was corrected to 57 % using a 2/3 scale model. The nominal turbulence in the empty test section was 0.1 % and the main flow velocity distribution 0.12 %, respectively. The jumpers were attached to an overhead three-component platform-balance with a modified "seat" and belts in the abdominal side of the hip. The set-up was pivoted close to the center of gravity in order to let the jumper to adjust the angle of attack. The force measurement accuracy was better than 5 %. The blockage ratio influenced on the accuracy. The sampling rate for the force measurements was 1 Hz. The force values were averaged for six seconds.

The main parameters in the ski jumper test conditions were as follows: kinetic pressure, q = 500 - 550 Pa, flow velocity v = 29 - 30 $m\ s^{-1}$ and Reynolds number Re = 3.5×10^{6}. The drag (Fx), lift (Fz) and pitching moment (My) were transformed into dimensionless form coefficients as follows: drag coefficient Cx = Fx / qS, lift coefficient Cz = Fz / qS and pitching moment coefficient Cmy = My / qSl, where l is the aerodynamic reference length and S the aerodynamic reference area. The lift to drag ratio L / D = Cz / Cx.

Each subject performed five actual flight phase tests with complete aerodynamic parameter measurements. L / D ratio was calculated for each sampling time and relevant kinetic pressure and wind flow conditions. Simultaneously, the flight phases were filmed with two video camcorders (JVC GR - S707), one through window from side view and one from front view inside the wind tunnel. The dimensions of the orthogonal reference scaling system for the position analysis were 2.90 m x 1.90 m x 1.05 m. 3 - D flight posture model with sixteen points (four from each ski, ankle joint, knee joint, shoulder and wrist from each side the body) was created with Ariel Performance Analysis System. In the flight phases when the L / D ratio was in maximum, the individual averaged positions for selected sample times were calculated for the angle of attack of skis, feet and upper body. The sweep angle of the skis (V - angle) and the distance of the ankle joints were also calculated.

The selected posture angles to describe the optimal flying posture in the middle part of the flight can be seen in Table 1 (Luhtanen et al., 1995b).

Table 1. Selected posture angles (Mean ± S.D.) of subjects during "actual flight"

Variable	Mean ± S.D.
Angle of attack of skis (AAS), degree	27.1 ± 3.0
Angle of attack of lower limbs (AALL), degree	41.8 ± 2.6
Angle of attack of trunk (AAT), degree	21.7 ± 3.3
Angle of attack of upper arm (AAUA), degree	22.7 ± 5.9
Angle of rotation of skis round the (ARS) longitudinal axis about horizontal level, right ski	26.8 ± 2.9
left ski	28.9 ± 6.4
Distance of ankle joints (DAJ), cm	27.9 ± 6.2
V-angle (VAN), degree	26.8 ± 2.9

The average lift-to- drag ratio was 1.25 ± 0.11 in the averaged posture described in Table 1. The lift and drag coefficients for polar curve were measured with a subject (A.N.) using a forced modified set-up. In the measurements, the angle of attack of system was changed so that the postures were corresponding to the early flight, middle phase and last part of the flight.

For simulation, the input variables were as follows: air density, initial velocity at starting gate, mass of the jumper-equipment system, friction coefficient, aerodynamic reference area, takeoff force, aerodymical parameters during gliding phases on the track and in air, sensitivity of lift to drag ratio for the head and side wind, profile of the jumping hill starting gate position according to the standards of the International Skiing Federation and head and side wind velocity. For simulation the linear and curvilinear parts of the up-hill were divided into 20 parts and the linear takeoff table into ten parts with specific input data.

The output variables were as follows: the tangential and normal component of the velocity at takeoff table, resultant velocity, release angle, instantaneous x-, y- and z- coordinates, v_{x-}, v_{y-} and v_{z-} components and resultant velocity as function of time (integrated for every 0.02 second). The length of a jump was defined as the length when the path of the jumper's center of gravity and the profile the of hill intersected.

RESULTS

Figure 1 and 2 show the length of jumps with a typical tangential release velocity of 84 kmh^{-1} and two takeoff velocities (2.6 ms^{-1} and 3.0 ms^{-1} perpendicularly to the takeoff table) in different wind conditions (-6, -4, -2, 0, 2, 4 and 6 ms -1) and mass of the jumper-equipment system (60, 65, 70, 75 and 80 kg).

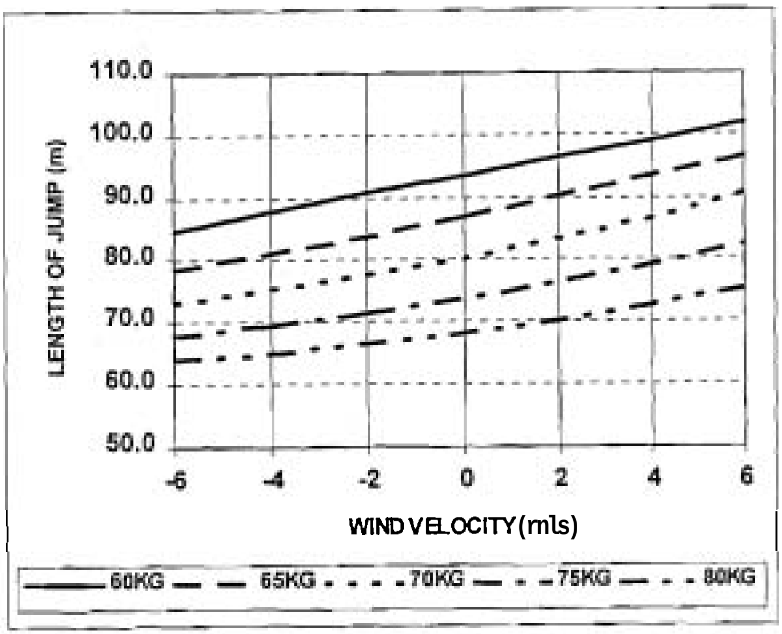

Figure 1. Length of jump with the tangential release velocity of **84** kmh^{-1} and takeoff velocity (perpendicular to the takeoff table) of 2.6 ms^{-1} in different wind conditions and mass of the jumpers.

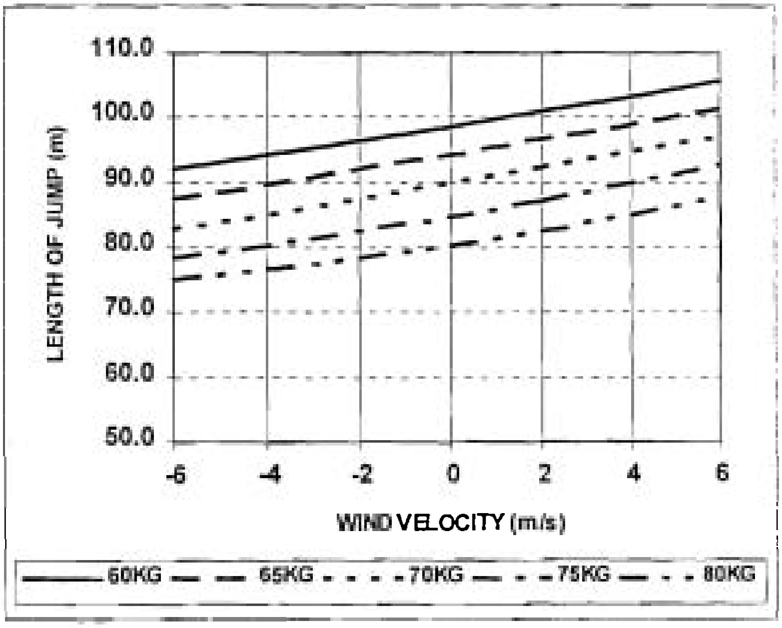

Figure 2. Length of jump with the tangential release velocity of **84** kmh^{-1} and takeoff velocity (perpendicular to the takeoff table) of 3.0 ms^{-1} in different wind conditions and mass of the jumpers.

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