INFLUENCE OF A SKI-JUMPER MODEL, SKIS AND SUITS ON AERODYNAMICAL CHARACTERISTICS IN SKI JUMPING

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Naked 2/3 scale model without and with reference skis, four different pairs of skis and two different suits were evaluated in the 2 * 2 m^2 low speed wind tunnel. The tests were carried out using 30–35 ms^{-1} flow speed equaling Reynolds number 2.4 * 10^6. The positions of angle of attack ranged from -8 degree to +12 degree. Reference position 0-degree equals incidence of 30 degree of plane defined by skis with zero flow speed. The aerodynamic characteristics were drag, lift and pitching moment, which were transformed into dimensionless coefficients. In general, it can be stated that 60 % of the aerodynamic forces were acting on the body of the model and 40 % on the skis. If the ski area increased by 1 % the aerodynamic forces increased 0.4 %. The relative increments in the length of the jump in a K 120 jumping hill with the skis A, B and C were 5.5 %, 6.2 % and 5.1 %, respectively. The effects of variation on air permeability of the suits were on the drag 7–12 % and lift 12–25 %.

KEY WORDS: ski jumping, aerodynamics, wind tunnel, drag, lift, pitching moment

INTRODUCTION: With the emergence of the V-style jumping technique, ski jump length was dramatically increased (Mahnke and Hochmuth, 1990). In order to counteract, two factors affecting on the aerodynamic efficiency were started to be regulated; the length of the jumping skis and the ski suit permeability. The first rule allowed the ski length to be one's body height plus 85 cm, the toe binding location was unregulated and the thickness of the suit was 8 mm and the permeability 30 $l/m^2/s$. The next rule changed the ski length to be height plus 80 cm, the binding location was set at 57 % of the ski length and the suit was not changed. At last, on the basis of the hypothesis that the ski length rule favored shorter jumpers over the taller jumpers, the 146 % rule and the change in suit (thickness 5 mm and permeability 40 $l/m^2/s$) were adopted provisionally for a trial year 1998–1999. This allowed jumpers taller than 173 cm to use longer skis while jumpers less than 173 cm were forced to use shorter skis than previously. The current 146 % rule seems unfair to the shorter jumpers. If also the jumper's weight would have been taken into account in the ski length optimization the ski length should have been 145 % of the height of the jumper (Noerstrud, 1996). The purpose of this study is clarify the substantial relationships of aerodynamic characteristics, ski length and suit permeability in the wind tunnel measurement using a 2/3 scale model.

METHODS: The equipment of the 2/3 model were as follows: skis, helmet, shoes and official competition clothing. The measurements were performed in a subsonic Göttingen type closed circle wind tunnel where the cross section in the measurement area was 3.68 m^2 (Luhtanen et al., 1996). The nominal turbulence in the empty measurement section was 0.1 % and the main flow velocity distribution 0.12 %, respectively. The model was attached to an overhead six-component platform-balance. The force measurement accuracy was better than 1 %. The blockage ratio was at most 5 %. The sampling rate for the force measurements was 1 Hz. The force values were averaged for six seconds.

After taring the actual measurements embarked upon with defining the baseline configuration. The actual measurements were with 2 degree interval from -8 degree to typical +8 degree the angle being the incidence of support strut. The typical angle of attack range of the ski-plane was 22–38 degrees. The main parameters in the ski jumper model test conditions were as follows: kinetic pressure, q = 500–550 Pa, flow velocity v = 30–35 ms^{-1} and Reynolds number Re = 2.4 x 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 was L / D = Cz / Cx.

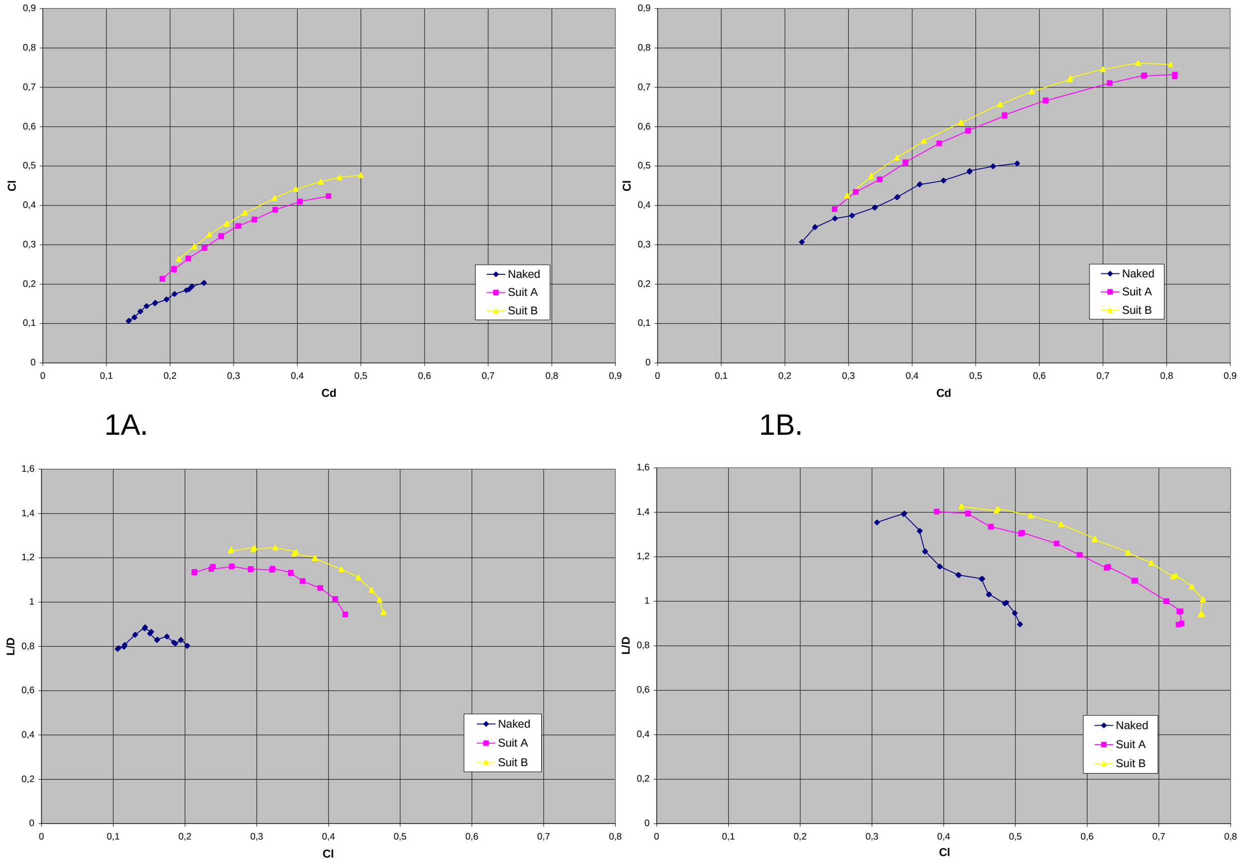
Measurements:

1. Two suit material (A and B of the same manufacturer) with the permeability of 40 $l/m^2/s$ were measured without and with skis. The ski length was 169 cm. The width was at front 71 mm, at binding 65 mm and at rear 71 mm. The frontal binding of the ski location was 57 %.
2. The skis were evaluated using the same reference suit (A) and compared to the skis used in the previous measurement. The new skis with the frontal binding location of 57 % were as follows:

- Ski ref: length 169 cm. width at front 71 mm, at binding 65 mm and at rear 71 mm.
- Ski A: length 170 cm, width at front 86 mm, at binding 78 mm and at rear 86 mm
- Ski B: length 175 cm, width at front 86 mm, at binding 78 mm and at rear 86 mm
- Ski C: length 180 cm, width at front 87 mm, at binding 78 mm and at rear 87 mm

For simulation of jump lengths, Aquila-simulator (Luhtanen et al., 1995) was applied. The simulator with the measured aerodynamic parameters was applied to Lillehammer K 120 jumping hill. The length of a jump was defined as the length when the path of the jumper's center of gravity and the profile of the hill intersected.

RESULTS: Polar curves were constructed for naked model and different suits without and with skis (Figure 1A and B). Lift to drag ratio curves related to the drag (Cd) and lift coefficient (Cl) was constructed (Figure 1C and D).

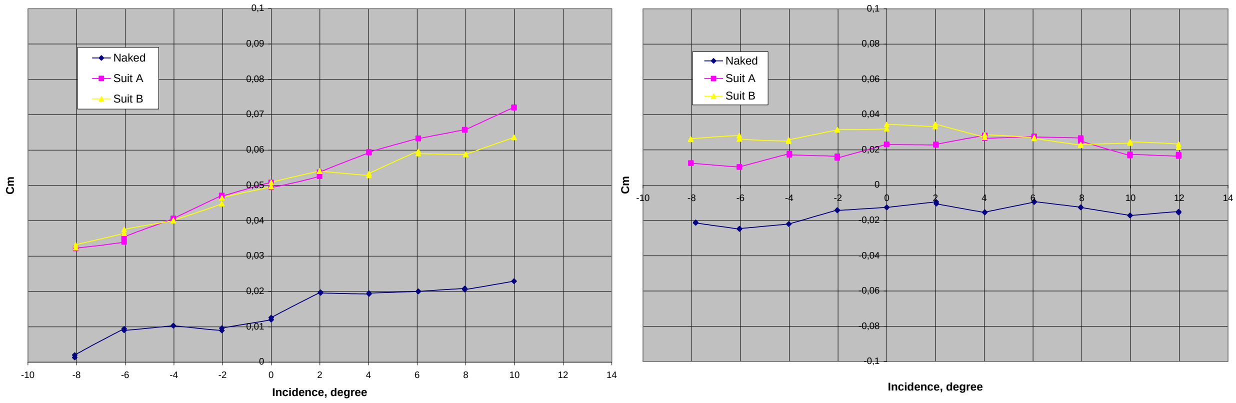


1A. 1B.

1C. 1D.

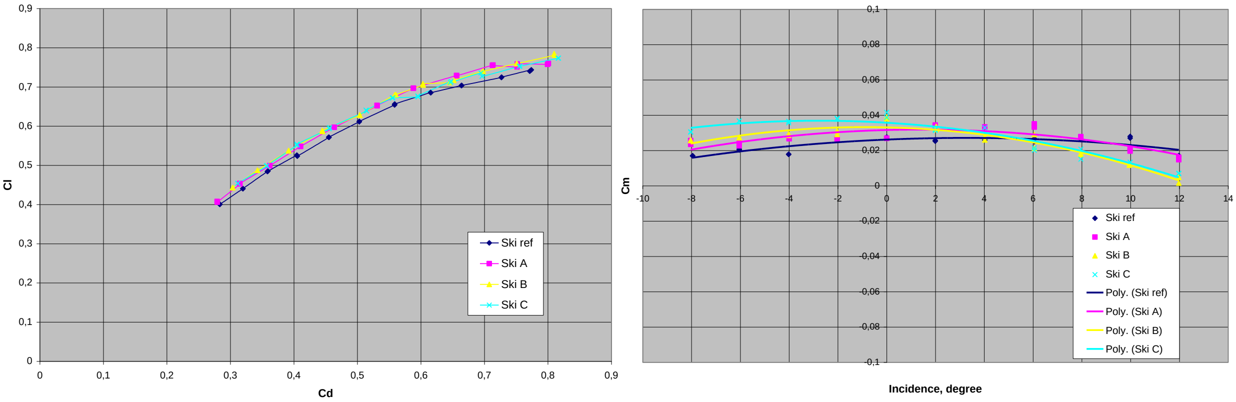
Figure 1 - Polar curves for naked model and different suits related to the drag (Cd) without skis (1A) and with skis (1B). Lift to drag ratio curves related to the lift coefficient (Cl) without skis (1C) and with skis (1D).

The pitching moment coefficients were constructed for different suits without and with skis related to the incidence (Figures 2A and B). Figure 3 represents the polars of different ski lengths, pitching moment coefficients and polynomial curve fitting for different skis related to the incidence.



2A. 2B.

Figure 2 - Pitching moment coefficients for different suits without skis (2A) and with skis (2B).



3A. 3B.

Figure 3. Polars of different ski lengths (3A) and pitching moment coefficients and polynomial curve fitting for different skis related to the incidence (3B).

The length of the ski does not differentiate the polar curve clearly (Fig. 3A). It can be observed that the longer the ski the higher its starting points (shallowest incidence) on the polar. If the aero force production of the skis is about 40 % and the difference in surface area between the shortest and longest ski is about 5 % the increase in the magnitude of aero force can be about 2 %. The pitching moment coefficient for different skis has been represented in Figure 3B. It is observable that the longer skis tend to have larger range of negative pitching moment coefficient slope against incidence (dCmy/dα).

To evaluate the magnitude of the aerodynamic forces of the body relative to the complete jumper-ski-system reference configuration was tested without and with skis. The results, lift (Cl), drag (Cd) and resultant force are presented in Figure 4. In general, it can be stated that 60 % of aerodynamic forces are acting on the jumper body and 40 % on skis. With shallow incidence angles (ski plane incidence 22 degree) the drag proportion of body is about 73 %. However, it decreases gradually when increasing incidence ending down to 57 % at steep angles (ski plane incidence 42 degree). The change of lift is opposite. At shallow angles the proportion of lift on the body is about 55 % and at steep angles it increases up to 60 %.

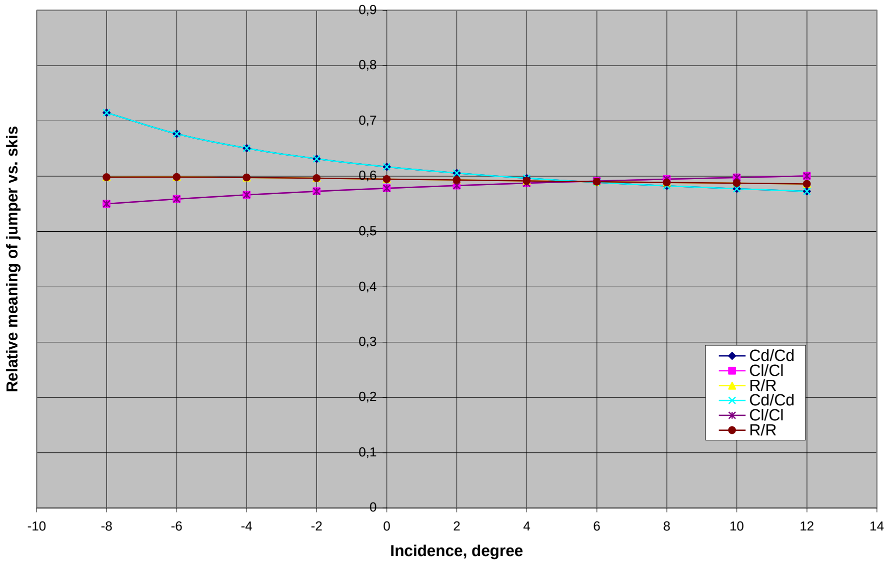


Figure 4 - The proportion of aerodynamic forces acting on the body of the jumper.

DISCUSSION: It has been shown that the lengths of the real and simulated jumps are in agreement on average by ±2.8 % (Luhtanen et al. 1995 and 1996). The Aquila-simulator takes into account all measurements explained in this study. The main result in this study was that 60 % of the aerodynamic forces are acting on the body of the jumper and 40 % on the skis. When comparing the length and the area of the skis A, B and C to the reference ski the relative increments in the length of the skis were 0.6 %, 3.6 % and 6.5 %, and in the surface area 21.3 %, 24.9 % and 28.5 %, respectively. If the ski area increased by 1 % the aerodynamic forces increased 0.4 %. The corresponding effects on the jump length were calculated for the Lillehammer K 120 jumping hill. The relative increments with ski A, B and C were 5.5 %, 6.2 % and 5.1 %, respectively. Concerning several jumping hills (K 90 and K 120) it was found that the increment of 22–29 % in ski area increased about 40 % in total aerodynamic forces adding jump length 9–12 %. Air permeability of a suit is officially measured in four points (left and right in chest and back). The extreme ranges in the 40 $l/m^2/s$ -suit were from 36.3 to 43.8 $l/m^2/s$. The effect of the large variation in air permeability was on the drag even 7–12 % and on the lift 12–25 %. It was also found that the force measurements are very sensitive to suit size and bubble formation in the back. Probably, the stiff suit materials are best for the stability of the flight.

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