RECENT FINDINGS CONCERNING AERODYNAMIC EFFECTS IN SKI-JUMPING

MAHNKE, R.; HOCHMUTH G.
Institut of Physical Culture and Sport
Leipzig
GDR

In the last few years there has been a rapid improvement of performance in ski-jumping. Flight postures have visibly changed, as regards both body configuration and ski attitudes. The most noteworthy developments are the latest variations in ski attitude, the spectacular V-form (Boklev-position), the oblique ski position to the flight path plane, and in general substantially broader ski attitudes than before. All these new ski attitudes variations contravene the current "Standards for Position and Movement" in force on which the scoring system of the jump is based: with the result that points are deduced. However, the gain in jumping distance for some jumpers more than outbalances the loss of points.

As so often in sport, the practice of sport has led to the discovery of new and more effective technical solutions which contradict current opinions and as a result the consequently new criteria on which the scoring system is based are necessary. Biomechanics should be applied in order to find out the causal relations involved in the more effective use of windforce; new recommendations should also be found for favourable flight postures and performance of the complete flight by means of wind tunnel experiments and trajectory simulations.

1. THE AIMS OF THE WIND TUNNEL EXPERIMENTS

The purpose of the wind tunnel experiments carried out were based on the following observations:

a) It must be assumed that by means of the latest ski attitudes and an increased extension of the body, the jumper/ski unit attains a wider lift and drag area and changes in the aerodynamic conditions. Wind force is increased as a result and greater jumping distance can be achieved.

b) It is to be expected that the important change in bodyform in the right angled projection will alter significantly the relationship, discovered until now, between clearly defined flight-posture features in the flight path (i.e. the angle of attack of the ski and the upper and lower parts of the body) and wind force. In other words, the effective angles of attack of the ski and body are well to be found in other areas than have been discovered up to now.

c) Finally, it is also worth carrying out tests to ascertain whether the effect of physical differences in the jumpers has significantly increased though important changes in body-form and increased diversity of body-form. Consequently it might be much more necessary than previously to determine the most favourable flight posture of a given jumper by means of individual wind tunnel experiments in conjuction with computer simulations (i.e. individual, "made-to-measure solutions).

The results of the first wind tunnel tests concerning the latest ski attitude variations carried out on two jumpers in 1988, confirmed the above mentioned observations. After this, further tests involving top-class jumpers were staged. The aim of these tests was to determine the individual effective flight posture for the formation of the middle flight segment. The starting point in these tests was the desire to find more effective, individual ski attitude variations in conjunction with good body postures which could be assessed as realizable according to the level of development and achievable capabilities of a given jumper.

2. DESIGN OF MEASUREMENTS AND PROCEDURES IN THE WIND TUNNEL AND COMPUTER SIMULATIONS

With the help of a special support the jumper is positioned in the wind tunnel's air current in such a way as to be able to form various flight postures which are approximately reproduceable. By adjusting axle 1 and 2 (Fig.1 and 2) it is possible to vary the ski and body positions to the air current it is on. Consequently, a complete series of measurements can be taken during the air current process. A control monitor is positioned in the jumper's field of vision below the jet on which he can check the side-view and top view of his flight position and correct the errors as they appear on the screen (Fig. 2). Sketches are made of the pictures taken by video-cameras and other data characterising the flight posture is determined, using the respective taken previously. The measurement series were set in such a way that first of all the typical flight postures which had been determined earlier from the analysis of the jumpers actual movement sequences were shown and then the body position, the ski position and the body configuration were varied.

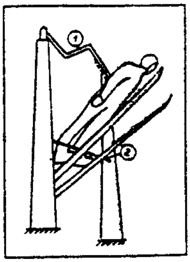


Figure 1:

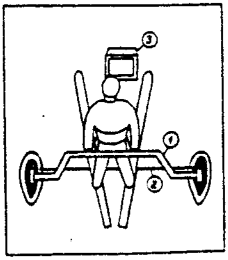


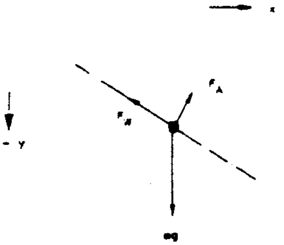
Figure 2:

In the presentation of the results as well as for the flight path calculations (computer simulated), those lift-and drag-coefficients are used which are based on the pressure, being recorded at the moment of the measuring process.

The wind tunnel measurements must be supplemented with flight path calculations (Computer simulations) because the quality of a flight generally is not calculable from the wind tunnel figures. The reason for this lies on the one hand in the fact that various combinations of lift and drag can lead to equal jumping distances, and on the other hand, a given flight position in the different flight segments can be judged as being good or bad to varying degrees. Consequently, the flight positions must be assesed in this unity as a course of movements (Mahnke 1983).

According to these facts, there is larger scope for equal variants in the composition of flight with varying combinations of lift and drag levels in conjunction with varying changes in the course of the flight.

For the flight path calculations a simplified model was used with which the jumper-ski system is taken as mass point for application (Fig.3). The computer simulation was carried out by the Simsyst Simulationssystem from Knauf/Schnabel (1989). (Mahnke 1989).



$$m\ddot{x} = F_A \frac{\dot{y}}{v} - F_W \frac{\dot{x}}{v}$$

$$m\ddot{y} = mg - F_A \frac{\dot{x}}{v} - F_W \frac{\dot{y}}{v}$$

$$F_A = c_A A \frac{\rho}{2} v^2$$

$$F_W = c_W A \frac{\rho}{2} v^2$$

$$q = \frac{\rho}{2} v^2$$

$$f_A = c_A \cdot A = \frac{F_A}{q}$$

$$f_W = c_W \cdot A = \frac{F_W}{q}$$

- m mass of the jumper/ski system
- g gravitational acceleration
- v velocity of the jumper
- c_A lift coefficient
- c_W drag coefficient
- A drag/lift area
- q pressure
- f_A, f_W coefficients related to the pressure

Figure 3: Model for the flight phase

According to the respective questions involved, different variants in the form of varying degrees of lift and drag in flight time were set up in the computer simulation. Using the established jump distances, the effects of the changes in flight path course carried out were determined against a set variant used for reference.

3. RESULTS

3.1. THE INFLUENCE OF SKI ATTITUDE ON WINDFORCE AND JUMPING DISTANCE

In comparison to the conventional, narrow and parallel ski attitude with a ski's-break distance between the skis (Fig. 4 with 10 cm), all other ski-attitude-variants researched show in some cases quite clearly even increased wind force. As a rule, wind force rises with the increase in distance between the ski. Oblique ski attitude variants produce greater wind force than the parallel (to the flight path plane) ski attitude; Boklev-form generally brings about the greatest increase in wind force however.

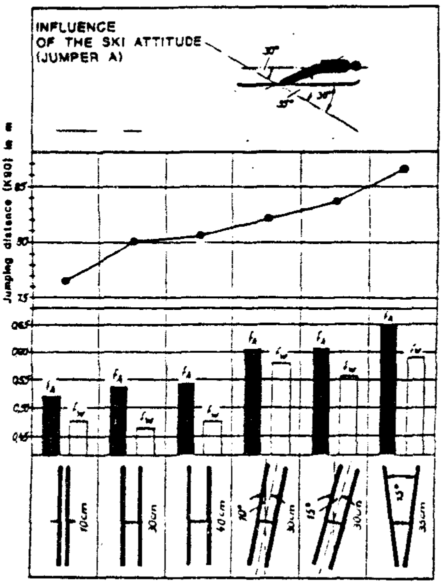


Figure 4:

Here, the rise in lift and drag occur almost to the same extent. These tendencies are clearly visible in Fig. 4, as they are in the other figures of the wind tunnel results. The results of the computer simulation (representation of the jumping distances achieved in Fig. 4) verify that these increases in lift and drag, while the lift-to-drag ratio remains the same or even increases, produces a clear increase in jumping distance.

The increase in distance as a result of the V-form in comparison to the conventional, narrow and parallel ski attitude would, according to the computer simulation on the normal jumping hill, amount to a good 10 metres. Nevertheless, the increase in distance is considerable at 7 metres with the oblique positioned skis.

It is understandable that, owing to this significant influence, it is rare to find ski attitudes in ski-jumping today where the distance between the skis is smaller than 25 centimetres.

3.2. INFLUENCE OF DIFFERENT PHYSIQUES

In Figures 5 and 6 the results of examination of two jumpers (Jumpers B and C) are compared. The comparison shows that for the same flight posture (same angle of attack of body and ski position, as well as similar ski attitude) in all stages of measurement, different lift and drag levels occurred (see Fig. 5). The figure for jumper B exceeded those of jumper C right through, in lift as well as in drag. At the same time however the degree to which wind force tended to be dependent on body and ski position was the same in both jumpers. A reason for this fact is obviously to be found in the different body form.

As a result of this jumper B achieves larger jumping distances with the same flight postures than jumper C. The difference can be as high as 3 metres on the normal jumping hill (in average 13 m). Jumper D achieves his optimum with quite an extended (stretched) flight position and an angle of attack for the lower half of the body of approximate 50°).

In both cases an increase in distance of 5 to even 7 metres is achieved by means of the V-form ski attitude.

The comparison conducted here draws our attention to the fact that a quantitative assessement of the effectiveness of flight postures can only be made with the help of wind tunnel experiments for the given jumpers.

3.3. THE DETERMINATION OF FAVOURABLE, INDIVIDUAL FLIGHT POSTURES

Using jumper D (top class) as the example, the results were as follow:
This jumpers' typical flight posture is characterised by a long extension of the body and large forward lean, during which he positions his skis oblique to the flight path. With this flight posture he achieves in the middle flight segment very good wind force figures and consequently large jumping distances.

However, this jumper could achieve even better results if he puts the skis in the V-form (Fig. 7). The increase in distance on the Normal Jumping Hill is, on the basis of computer simulation, to be estimated as approx. 5 metres. If we compare the wind force figures he achieved with the V-form ski attitude with those of jumpers B and D (e.g. with 35° of ski angle position) then the overall higher efficiency of his flight position is clearly shown.

During the search for remaining reserves to achieve further perfection of jumper D's flight posture, interesting observations were made.

With an oblique ski attitude, both windforces figures - lift and drag - rise by approximate 10% with an increase in the angle position (angle of attack) of the body (lower body from 45° to 52° and upper body from 30° to 35°).

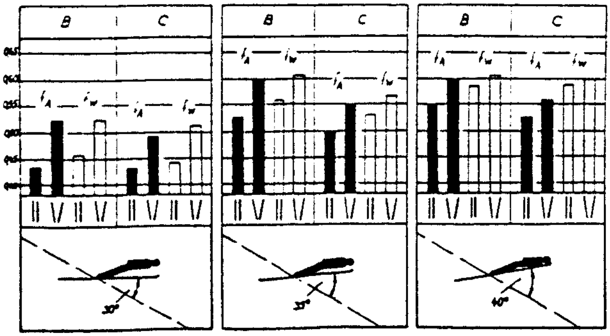


Figure 5: INDIVIDUAL DIFFERENCES between Jumper B and C
Coefficients fA and fW

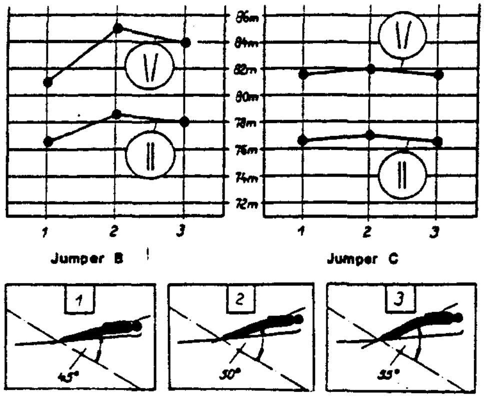


Figure 6: INDIVIDUAL DIFFERENCES between Jumper B and C
INFLUENCE on JUMPING DISTANCE

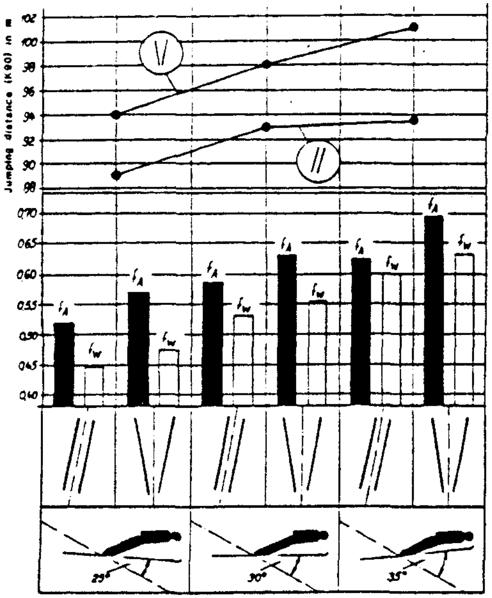


Figure 7: JUMPER D (top class) oblique and V-Form

This causes an increase in distance of 5 metres. As a result the assumption could be confirmed that jumper D has to suffer a loss of distance achieved because he often tends to reduce the angle of attack (angle position in the course of the flight.

In a similar way, the effects of subsequent typical signs in the course of the movement of this jumper could be quanitified; signs which until now had been assesed as having negative effect.

Above all, this was evident in the reduction of the ski angle (position) in the second half of the flight.

As with the oblique ski attitude, Jumper D also achieves with the V-form flight posture with approximate 50° angle of attack of the lower part of the body the longest figures in lift and drag jumping distances. Should he have to exceed these levels however, the figures would be much more uneffective (see Fig. 8).

The drag figures increase dramatically and this causes considerable losses in distance.

These observations lead to a statement of general validity to the effect that especially with the V-form ski attitude a given optimal angle of attack of body position should (under no cirumstances) be exceeded. This fact is confirmed in practice in the execution of skijumping in so far as those jumpers who prefer the V-Form ski attitude, do sometimes not obtain the large distances that they might otherwise achieve, because their angle of attack of the body was to large during the flight.

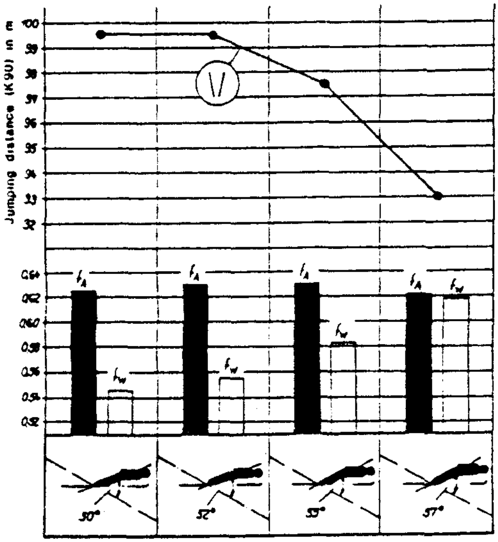


Figure 8: JUMPER D (top class)/ - Form
INFLUENCE of the angle of attack of the lower body

4. FINAL OBSERVATIONS

The result of the wind tunnel experiments carried out and the computer simulations clearly show that with the new ski attitude variants, the aerodynamic effects can be very efficiently used for the achievement of greater jumping distances.

This represents a progress in the development of ski jumping technique which cannot be stalled any longer and which the jumpers are naturally exploiting.

The current rules and regulations on posture and movement in the judging of jump - execution (Article 431.2.1. of the International Ski Competition rules of the FIS) conflict with this development. These regulations ought to be changed and adapted to the development further, for these developments will continue to disregard the rules anyway.

REFERENCES

MAHNKE,R.: Investigations into the Criteria for the effective Take off-Transitonal - and Flight phase - techniques in ski-jumping - 1983-Leipzig, FKS, Diss.A

MAHNKE,R.: The use of Computer Simulation in Skijumping in the determination of effective flight posture 1990, Leipzig, Training und Wettkampf, H 2/3, 148/165.