ANALYSIS OF KINEMATIC VARIABLES AND THEIR RELATION TO THE PERFORMANCE OF SKI JUMPERS AT THE WORLD CHAMPIONSHIP IN SKI FLIGHTS AT PLANICA IN 1994

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Abstract

The objective of this study has been to establish on a sample of the best ski jumpers (n=28) participating in the World Championship in ski flights at Planica in 1994 (K=180 m) by means of a 3-D kinematic analysis the relation between the selected kinematic parameters of the jump of a ski jumper and his performance from the aspect of the flight length.

By means of correlation analysis and univariate factor analysis of variance, some statistically significant relations of the kinematic variables to the length of the jump ($p<.05$) were established. The most important predictor of a successful jump was the angle of elevation in the middle part of the jump ($r = -.78$). The results have also shown that in order to achieve a high performance level from the aspect of the length a ski jumper must maximise the resultant of the speed of movement of the body's centre of gravity in the first part of the flight; maximise the horizontal component of the speed of movement of the body's centre of gravity during the entire flight and in particular in the first part of the flight; decrease the angle between the longitudinal and horizontal axis of the body, above all in the middle part of flight; decrease the angle between the longitudinal axis of the body and the skis in all phases of the flight; optimise the angle between the longitudinal axis of the upper part of the body and the skis in the take-off phase and minimise it in the middle part of the flight, where this requirement is combined with the requirement for the minimisation of the angle between the skis and the horizontal.

Keywords: ski flights, kinematic variables, analysis, performance

Zusammenfassung

ANALYSE KINEMATISCHER VARIABLEN UND IHRE AUSWIRKUNG AUF LEISTUNG VON SKISPRINGERN BEI DER SCHISPRUNGWELTMEISTERSCHAFT IN PLANICA IM JAHRE 1994

Zielsetzung war auf den Mustersatz der besten Schispringer (n=28), Teilnehmer an den Schisprungweltmeisterschaft in Planica im Jahre 1994 (K=180m), aufgrund der kinematischen 3-D-Analyse das Verhältnis zwischen den betreffenden Sprungparametern einzelner Schispringer und betreffender Sprungweitleistung festzustellen. Durch Korrelations- und Einfaktorenanalyse der Variablen wurden statistisch bedeutende Beziehungen zwischen kinetischen Variablen und Sprungweite ($p<0,05$) ermittelt. Der bedeutendste Prädiktor eines erfolgreichen Schisprunges war der Elevationswinkel im mittleren Sprungteil ($r=0,78$). Die Ergebnisse zeigten auch, dass wenn ein Schispringer eine hohe Sprungerfolgsrate und Sprungweite erreichen will, soll er die Bewegungsresultante vom Körperschwerpunkt, aus im ersten Sprungteil maximieren; horizontale Komponente der Schnellbewegung vom Körperschwerpunkt während des Sprunges maximieren; den Winkel zwischen der Körperlänge und Horizontalachse, besonders im mittleren Sprungteil senken; den Winkel zwischen der Körperlänge und Schier in allen Sprungteilen senken; den Winkel zwischen der Oberteil-Körperachse und Schier beim Absprung optimieren und ihn gleichzeitig im mittleren Sprungteil minimieren, weil er mit dem zu minimierenden Winkel zwischen den Schiern und der Horizontalachse zusammenfällt.

Schlüsselwörter: Schiflug, kinematische Variablen, Analyse, Leistung

Introduction

With the breakthrough of the so-called "V" technique in the 1991/92 season, the technique of ski jumping has changed fundamentally. These changes are certainly most apparent in the most difficult inertial conditions and at the most demanding competitions. For this reason, the world championship in ski flights has been selected for the research into the characteristics of ski jumping technique in ski flights. The wide variety of ski-jumping technique, which was subjected to many research works in its history (Komi et al., 1974; Baumann, 1979; Vaverka, 1994; Jošt, 1990; Jošt, 1994; Hubbard et al., 1989; Hiroshi, 1995; Mahnke, 1990; Tavernier, 1993; Virmavirta, 1991; Watanabe, 1993; Yeadon, 1989) is manifested in ski flying.

The objective of this research has been to analyse the selected kinematic variables of the technique of ski flights defined in the take-off and flight phase, and to establish their relation to the performance of ski jumpers at the World Championship at Planica in 1994.

METHODS OF RESEARCH

In the research, ski jumps of 28 ski jumpers participating in the World Championship in ski flights at Planica on 20th March in 1994, K=185 m were analysed. With respect to the length of the jump, the ski jumpers were divided into three quality groups (above-average - B, n=7; average - M, n=14; and below average - L, n=7).

The data on the length of the jumps and approach speeds were taken from the official results of the world championship. The data on the body height and weight were taken from the official data of the FIS Bulletin.

Kinematic parameters of movement were measured by means of 3-D video analysis (CONSPORT, Prague, the Czech Republic). The filming was carried out by three pairs of PANASONIC AG455 video cameras (SVHS), with a shooting frequency of 25 frames per second. The first pair of cameras filmed the last 10 m of the jumping-off platform; the second pair of cameras filmed the first 10 m of the flight; and the third pair of cameras filmed the flight of the ski jumper at a distance of 75 up to 85 m from the edge of the platform. In each pair of cameras, cameras were positioned approximately perpendicular to each other.

The last 10 meters of the take-off platform was calibrated by two cubes (square side of 1 m). One cube was placed at the very edge of the take-off platform and the second in a direction of the starting point that the distance between their most exposed points was 8 meters at the ground level. Care was

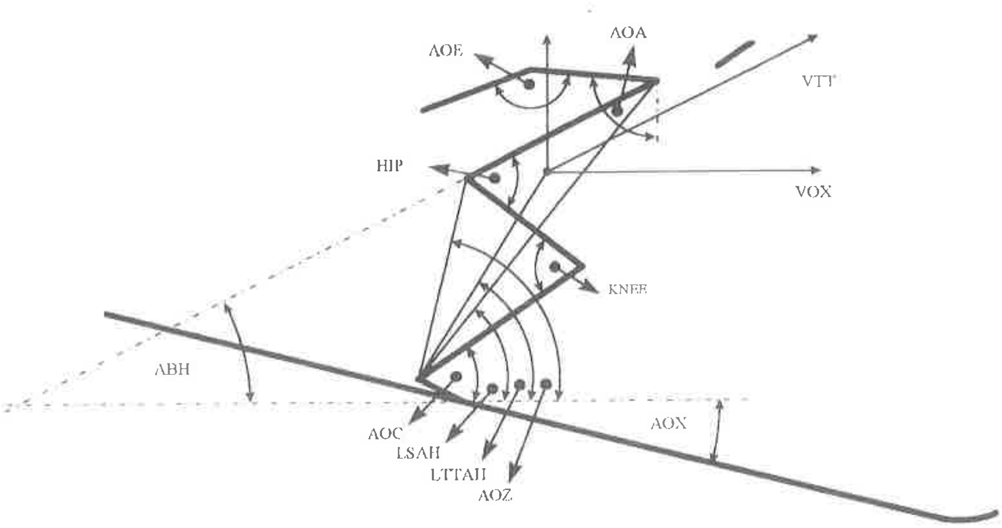

Figure 1: Graphical representation of the selected kinematic variables in the support phase of the take-off.

Where it means:

KNEE	-	knee angle
AOC	-	angle between the shank and the horizontal axis
LSAH	-	angle between the line which connects the axis of the ankle joint with the shoulder axis and horizontal axis
LTTAH	-	angle between the line which connects the body's centre of gravity with the axis of the ankle joint and the horizontal axis
AOZ	-	angle between the line which connects the hip joint with the axis of the ankle joint and horizontal axis
HIP	-	hip angle
ABH	-	angle between the longitudinal axis of the upper part of the body and the horizontal axis
AOA	-	angle between the upper arm and the vertical axis
AOE	-	angle between the upper and the lower arm
AOX	-	angle between the longitudinal axis of the skis and the horizontal axis
VTT	-	speed of movement of the body's centre of gravity
VOX	-	horizontal component of the speed of the body's centre of gravity

taken that the cubes were strictly parallel to the approaching direction and that the lateral planes were vertical. The inclination angle of the platform was obtained as well. The position of the extreme outside 8 points of the space defined by both cubes were used to calibrate the space. The cameras were synchronized due to the first frame when the jumper took off from the platform.

The first ten meters of the flight phase were calibrated by employing the cube placed at the edge of the take-off platform (not removed from the calibration of the previous space) and the special cross placed at the end of this zone. A 4 meter long horizontal bar was fixed 6 meters high on a 8 meter high vertical bar. The vertical bar was placed vertically (proved by an inclination meter) with the horizontal bar perpendicular to the jumping direction. The cross was mounted fixed with the ropes connected to the ends of the horizontal bar. On the cross, four points were identified: at the ends of the horizontal bar, at the top of the vertical bar and at a point 4 meters below the top of the vertical bar. These points on the cross and the four points of the cube's plane perpendicular to the jumping direction at the edge of the take-off platform (the very same as the former calibration) were used for the space calibration. The standing point of the cross was in a line with the approaching direction. The distance and the inclination between the edge of the take-off platform and the standing point of the cross were measured. The cameras were synchronized in the first frame when the jumper left the platform.

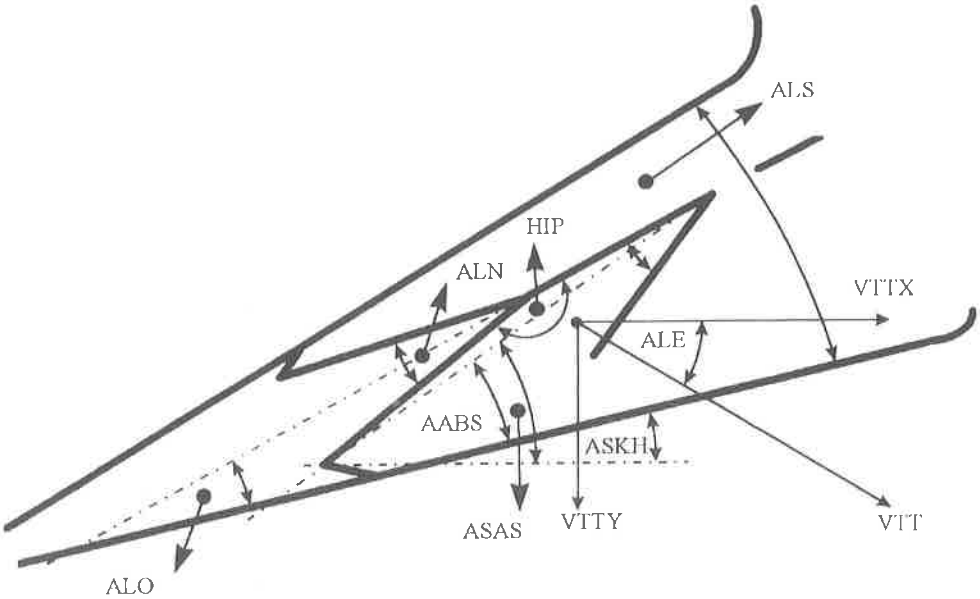

Figure 2: Graphic representation of the selected kinematic variables in the flight phase.

Where it means:

ALE	-	angle between the chord of the trajectory of movement of the body's centre of gravity and horizontal axis
VTT	-	speed of movement of the body's centre of gravity and skis
VTTX	-	horizontal component of the speed of movement of the body's centre of gravity
VTTY	-	vertical component of the speed of movement of the body's centre of gravity
ALS	-	angle between the skis in the horizontal plane
HIP	-	angle at the hip
AABV	-	angle between the arm (wrist-shoulder line) and longitudinal axis of the upper part of the body in the sagittal plane
AABH	-	angle between the arm (wrist-shoulder line) and longitudinal axis of the upper part of the body in the horizontal plane
ASAS	-	angle between the line which connects the ankle and shoulder joint and the horizontal axis
AABS	-	angle between the line which connects the ankle and shoulder joint and the longitudinal axis of the skis in the sagittal plane
ALO	-	angle between the longitudinal axis of the upper part of the body and skis in the sagittal plane
ALN	-	angle between the legs (ankle-hip line) in the horizontal plane
ASKH	-	angle between the horizontal axis of the skis and horizontal axis

For the calibration of the space in the flying phase, the cross was placed at 75 and 85 meters, according to the original markers on the jumping hill. In both positions, the cross was fixed vertically with the horizontal bar perpendicular to the approaching direction. The cross standing points were aligned with the approaching direction. A distance and inclination between standing points were measured. Cameras were synchronized with a help of two reflectors directed to each camera which triggered simultaneously during the flight through the measured space.

Digitalisation of the data was performed manually. For kinematic analysis, a 16-segment 3-D model (head, shoulders, upper arm, lower arm, trunk, hips, thigh, shank, ski) was employed, determined by 18 points which represent the joints, extreme points of the limbs, and the skis. Each camera view (2D) was digitized separately followed by 3D coordinates calculation. The 3D coordinates were smoothed afterwards (each axis separately) with a low-pass digital filter (cut-off frequency 7 Hz). These data were then used for the calculation of parameters.

In the support phase of the take-off, i.e. at the first point (8 m before the edge of the jumping-off platform) and second point (1 m before the edge of the jumping-off platform), the following set of kinematic parameters (Figure 1) was defined:

All the above mentioned angles were measured in the sagittal plane on the right side of the body.

In the phase of the flight, i.e. at the third point (8 m away from the edge of the jumping-off platform) and the fourth point (78 m away from the edge of the jumping-off platform), the analysis of the jump technique was carried out by means of the following kinematic variables (Figure 2).

For the establishment of statistical significance of the differences between the groups, a one-factor analysis of variance (ONEWAY) was used. The significance of the correlation between the kinematic variables and the length of the jump was established with Pearson's correlation coefficient. In the both statistical procedures, the criterion of statistical significance was adopted with a 5% two-sided alpha error.

Results and interpretation

Analysis of the Criterion and Morphological Variables

The results of the one-factor analysis of variance carried out on the variables of the length of the jump, body height (ATV) and weight (ATT) are shown in Table 1.

Table 1: Results of the one-factor analysis of variance of the criterion and morphological variables; L - below-average group, M - average group, B - above-average group; Mean - arithmetic mean of the group; SD - standard deviation within the group; F - Prob. - significance of the F-test, where the asterisk (*) means statistically significant differentiation between the quality groups of ski jumpers

	L		M		B		
	Mean	SD	Mean	SD	Mean	SD	F prob
DSKOKA1	108.8	10.8	131.7	10.8	173.8	12.8	0.00*
DSKOKA2	101.5	6.1	129.4	12.9	170.5	15.4	0.00*
ATV	173.0	9.3	178.5	6.4	177.0	3.5	0.29
ATT	62.8	8.5	67.9	5.0	64.1	4.1	0.25
ZHIT1	28.40	0.19	28.48	0.12	28.33	0.32	0.27
ZHIT2	28.44	0.29	28.70	0.16	28.74	0.14	0.01*

The differentiation of the defined quality groups of ski jumpers in the variables of the length of the ski jump was statistically significant. The difference in the average lengths of the jumps between the extreme groups amounted in the first jump to 75 m, and in the second to 69 m. Within morphological variables of the body height (ATV) and body weight (ATT), no statistically significant differences were established.

In the second ski flight, the approach speed was the factor in which statistically significant differences between the below-average group of ski jumpers on the one hand and the average and above-average group on the other hand occurred. It has already been established in several researches in which the authors established statistically significant correlation between the approach speed and the length of the jump (Vaverka, 1987; Jošt, 1990) that the approach speed of ski jumpers is a significant indicator of their performance.

Results of the Kinematic Analysis in the Take-Off Phase

Table 2 shows the results of the single-factor analysis of variance and correlation between the criterion variable and the kinematic parameters defined in the support phase of the take-off, 8 m and 1 m before the edge of the jumping-off platform in the first (1) and second jump (2).

The angle between the thighs and shanks (KNEE) shows that 8 m before the edge of the jumping-off platform the ski jumpers were still in the so-called inrun crouch position. There followed rapid extension of the legs at the knee joint which reached, 1 m in front of the edge of the jumping-off platform, the average value of 139 degrees in the first jump and 143 degrees in the second jump. The average values of this variable are congruent with the results (Jošt, 1990) obtained in the analysis of the ski jumps at the World Championship in Ski Flights at Obersdorf in 1988.

Table 2 - first part: Correlations between the length of the jump and kinematic parameters (r) and the results of the one-factor analysis of variance carried out on the kinematic parameters in the support phase of the take-off of ski jumpers (8m and 1m in front of the edge of the jumping-off platform), World Championship in flights, Planica 1994, K185m; L - below-average group, M - average group, B - above-average group; Mean - arithmetic mean of the group; SD - standard deviation inside the group; F -prob. - significance of the F test, where the asterisk (*) means statistically significant differentiation between the quality groups of ski jumpers or statistically significant correlation (r)

		L		B		M		
	r	Mean	SD	Mean	SD	Mean	SD	F prob.
KNEE8M1	.10	80.2	9.1	84.9	6.2	82.1	6.0	0.31
KNEE8M2	.00	79.0	7.4	80.8	8.0	81.8	3.9	0.77
KNEEIMI	-.07	140.6	8.2	138.5	8.2	138.7	6.4	0.82
KNEEIM2	-.03	143.4	10.5	144.5	5.8	144.2	7.5	0.94
AOC8M1	-.14	49.9	7.9	51.1	5.1	47.8	3.0	0.44
AOC8M2	.07	51.3	4.9	51.9	5.8	53.4	3.7	0.73
AOC1M1	-.19	65.8	5.7	66.4	5.7	65.7	4.6	0.94
A0C1M2	-.10	65.6	8.5	66.6	4.5	65.6	9.3	0.94
LSAH8M1	-.12	52.0	6.8	53.1	5.6	49.5	5.1	0.42
LSAH8M2	-.09	54.4	4.0	55.3	2.9	55.5	3.5	0.80
LSAHIM1	-.20	57.8	2.5	57.9	4.2	57.0	4.0	0.87
LSAHIM2	-.11	59.0	5.0	59.8	3.8	59.1	5.1	0.89
LTTAH8M1	-.25	69.5	7.2	70.0	5.3	65.8	4.2	0.25
LTTAH8M2	-.02	71.8	4.0	72.7	4.1	73.2	3.0	0.79
LTTAHIM1	-.28	69.3	2.0	70.6	3.6	69.0	3.2	0.48
LTTAHIM2	-.09	69.3	4.9	69.9	2.8	69.9	6.2	0.96
AOZ8M1	-.36*	104.7	7.1	103.4	5.3	100.3	3.9	0.30
AOZ8M2	-.02	107.8	2.1	106.8	4.4	108.1	4.4	0.73
AOZIMI	-.21	84.8	3.4	87.1	4.4	85.5	3.6	0.40
A0Z1M2	-.12	83.9	5.8	84.6	3.2	83.8	5.6	0.90
HIP8M1	.35*	26.4	3.8	30.3	4.9	30.0	4.7	0.15
HIP8M2	-.23	29.1	4.6	29.0	3.7	28.1	3.8	0.86
HIPIM1	.05	91.0	12.0	84.7	13.8	86.8	15.1	0.58
HIPIM2	.02	96.4	9.9	96.7	8.4	96.4	7.3	0.99

Table 2 - second part: Correlations between the length of the jump and kinematic parameters (r) and the results of the one-factor analysis of variance carried out on the kinematic parameters in the support phase of the take-off of ski jumpers (8m and 1m in front of the edge of the jumping-off platform), World Championship in flights, Planica 1994, K185m; L - below-average group, M - average group, B - above-average group; Mean - arithmetic mean of the group; SD - standard deviation inside the group; F -prob. - significance of the F-test, where the asterisk (*) means statistically significant differentiation between the quality groups of the ski jumpers or statistically significant correlation (r)

		L		B		M		
	r	Mean	SD	Mean	SD	Mean	SD	F prob.
ABH8M1	-.14	4.8	3.5	4.5	1.8	4.7	2.4	0.96
ABH8M2	-.07	3.2	1.5	3.6	1.6	3.2	2.0	0.76
ABHIM1	.01	14.8	6.3	12.4	8.7	12.0	7.4	0.74
ABHIM2	-.08	17.9	7.2	17.7	6.8	16.7	5.9	0.93
AOA8M1	.23	80.3	4.2	81.3	4.2	81.5	6.1	0.86
AOA8M2	-.06	82.3	4.9	78.8	3.7	81.5	4.0	0.13
AOAIM1	.14	82.6	6.0	89.3	7.4	84.8	8.8	0.11
AOAIM2	.14	89.6	6.7	86.7	8.1	91.1	9.9	0.47
AOE8M1	.22	168.6	3.2	168.5	4.3	171.1	6.6	0.47
AOE8M2	.14	167.5	5.9	166.7	4.8	170.8	4.6	0.23
AOEIM1	-.11	167.6	6.2	165.7	5.2	165.1	5.3	0.62
AOE1M2	.06	167.4	6.1	169.4	4.7	168.9	5.1	0.70
AOX8M1	-.44*	13.3	2.3	13.3	1.5	11.0	1.5	0.02*
AOX8M2	.10	15.1	1.1	15.0	1.2	15.5	1.4	0.69
AOXIM1	-.07	13.4	1.5	13.0	1.7	12.9	1.7	0.81
AOXIM2	-.02	13.8	1.6	13.9	1.0	13.5	1.1	0.79
VTT18M1	-.12	31.3	0.3	31.3	0.4	31.3	0.5	0.97
VTT18M2	.54*	31.6	0.5	32.0	0.4	32.3	0.3	0.02*
VTTIIMI	-.08	28.9	0.4	29.0	1.2	28.9	2.0	0.99
VTT11M2	.31	28.9	0.4	29.7	0.7	29.4	0.5	0.06
VOX8M1	-.07	30.6	0.3	30.6	0.4	30.6	0.4	0.97
VOX8M2	.56*	30.9	0.4	31.2	0.4	31.6	0.3	0.02*
VOXIM1	-.08	28.8	0.4	28.8	1.2	28.8	2.0	0.99
VOXIM1	.31	28.8	0.3	29.5	0.7	29.2	0.8	0.07

The angle between the shanks and the horizontal (AOC) showed a significant increase (from 12 to 16 degrees) of the average values in the measured 7-m section on the jumping-off platform. By moving the shank backward the ski jumpers balanced the complex equilibrium situation immediately before leaving the platform. The differences between the defined quality groups of the ski jumpers were statistically irrelevant.

The variable which in general indicates the transfer of the body's centre of gravity in the forward direction (LTTAH) confirmed the assumption on the low validity level of this variable in terms of forecasting the performance in the ski jump length.

The angle ABH which indicates the opening of the upper part of the body had no statistically significant effect on the length of the jump.

In the variable showing the speed of movement of the body's centre of gravity in the horizontal direction, a statistically significant average increase between the below-average and above-average group, and at the same time also a statistically significant correlation with the jump length, occurred in the second jump. From the aspect of performance it is important that during the take-off ski jumpers maintain the highest possible approach speed which will provide the best possible starting point for the transition into the flight phase (Vaverka, 1987).

Results of the Analysis of Kinematic Parameters in the Flight Phase

The results of the kinematic analysis of the parameters defined in the flight phase (8m-A and 78m-B after leaving the edge of the jumping-off platform) are shown in Tables 3 and 4.

The angle of elevation (ALE), which shows the angle between the horizontal axis and the tangent of the trajectory of the resultant speed of movement of the body's centre of gravity (VTT), was the most important predictor of competition performance of ski jumpers in the middle part of flight. The above-average group of ski jumpers flew at a smaller angle of elevation. The difference between the above-average and the below-average group of ski jumpers was approximately 1.5 degrees.

The resultant speed of movement of the trajectory (VTT) in the middle part of flight (78 m after leaving the jumping-off platform) was larger (see Table 3) than in the take-off phase (8 m after leaving the jumping-off platform). The increment in speed was large (slightly less than 6 m/s on average). The approach speed was also considerably higher than the take-off speed. However, it was slightly lower than the speed measured in the middle part of the flight.

Table 3: Results of the correlation between the length of the jump and defined kinematic parameters (r) and the results of the one-factor analysis of variance carried out on the kinematic parameters in the flight phase (at a distance 8m-A and 78m-B away from the edge of the jumping-off platform); World Championship in ski flights, Planica 1994, K185m; L - below-average group, M -average group, B -above-average group; Mean - arithmetic mean of the group; SD - standard deviation inside the group; F - prob. - significance of the F-test, where the asterisk (*) means statistically significant differentiation between the quality groups of ski jumpers or statistically significant correlation (r)

		L		B		M		
	r	Mean	SD	Mean	SD	Mean	SD	F prob.
ALEA1	-.05	18.80	0.84	18.88	1.00	18.70	0.77	0.92
ALEA2	.14	18.91	0.88	19.26	0.73	19.46	1.02	0.49
ALEB1	-.72*	35.18	0.87	34.36	0.52	33.82	0.56	0.00*
ALEB2	-.78*	35.33	0.35	34.64	0.43	33.85	0.71	0.00*
VTTAI	.18	24.15	0.24	24.23	0.39	24.27	0.88	0.89
VTTA2	.38*	24.36	0.28	24.26	0.46	24.56	0.70	0.48
VTTB1	.02	30.08	0.65	30.74	0.81	30.21	0.97	0.16
VTTB2	.06	29.56	1.25	29.78	1.09	29.55	1.21	0.88
VTTXA1	.18	22.86	0.28	22.93	0.44	22.98	0.76	0.90
VTTXA2	.36*	22.95	0.44	22.91	0.45	23.14	0.69	0.65
VTTXB1	.24	24.58	0.64	25.38	0.73	25.10	0.78	0.06
VTTXB2	.20	24.25	1.02	24.50	0.92	24.54	1.05	0.84
VTTYA1	-.02	-7.76	0.32	-7.82	0.35	-7.78	0.55	0.92
VTTYA2	-.32	-7.87	0.36	-7.97	0.29	-8.17	0.44	0.33
VTTYB1	.44*	-17.32	0.46	-17.34	0.44	-16.81	0.64	0.08
VTTYB2	.31	-17.17	0.66	-16.90	0.63	-16.46	0.70	0.15

(*) r value = .36; p = 0.05

Similar tendencies were also established in the horizontal component of the speed of movement of the body's centre of gravity (VTTX). This component gradually decreased from the point of ascent 8 m after the take-off from 30.6 m/s (8 m before the edge of the platform) down to 28.8 m/s (1 m before the edge of the take-off platform), and to 22.9 m at the point situated 8 m away from the edge of the take-off platform. At the point 78 m after the take-off it even increased to an average 24.5 m. This phenomenon of horizontal speed increase is in all probability the result of aerodynamic effects of the acting forces, among which the horizontal component of aerodynamic thrust probably contributed to the largest extent. Basically, in this extremely demanding aerodynamic inertial system the effects characteristic of sailing occurred. In fact, the ski jumper who successfully utilised the aerodynamic thrust, was actually increasing the horizontal speed of the flight and was thereby reducing the angle of elevation.

Table 4: Representation of the parameters showing the geometric dimensions of the movement of ski jumpers in the flight phase (L - below-average group, M -average group, B - above-average group of ski jumpers); r - coefficient of correlation with the length of the jump (r value = .36; p = 0.05); Mean - arithmetic mean of the group; SD - standard deviation; F - prob. - statistical significance of the differentiation between groups, World Championship in ski flights, Planica 1994, K185, first series (1), second series (2), point A - 8 m away from the edge of the jumping-off platform, point B - 78 m away from the edge of the jumping-off platform.

		L		B		M		
	r	Mean	SD	Mean	SD	Mean	SD	F prob.
ALSAI	.27	2.35	1.88	2.73	1.24	3.56	1.22	0.36
ALSA2	.09	1.85	0.71	2.17	1.27	2.15	0.93	0.80
ALSB1	.16	17.45	8.05	23.63	5.94	21.04	6.15	0.13
ALSB2	.50*	16.20	8.54	20.66	8.27	25.37	6.58	0.13
HIPAI	-.05	150.94	9.76	143.61	9.72	146.30	4.79	0.23
HIPA2	.19	139.30	6.91	143.37	11.66	146.4	9.73	0.43
HIPB1	.42*	167.0	18.44	171.63	4.08	175.61	6.49	0.31
HIPB2	-.03	172.13	3.94	171.75	7.61	171.07	3.43	0.95
AABVA1	-.40*	24.41	8.74	18.11	7.28	15.34	8.72	0.12
AABVA2	.16	9.43	7.07	16.07	11.05	17.32	9.44	0.25
AABVB1	-.15	6.93	3.10	7.22	3.64	5.24	4.24	0.50
AABVB2	-.15	11.20	10.17	6.76	3.39	9.10	7.86	0.35
AABHA1	-.22	8.82	3.02	7.32	3.03	7.36	1.44	0.49
AABHA2	-.14	7.81	2.66	8.29	3.36	7.08	3.20	0.72
AABHBI	-.23	19.93	8.24	13.25	5.71	16.90	5.32	0.08
AABHB2	-.13	14.83	10.48	16.10	7.57	12.05	5.91	0.54
ASASA1	-.07	44.28	3.85	43.66	3.78	44.18	3.33	0.92
ASASA2	-.16	45.27	4.01	42.91	4.49	43.14	3.11	0.45
ASASB1	-.57*	15.46	10.82	7.52	4.12	6.41	3.96	0.02*
ASASB2	-.08	10.83	5.81	11.88	4.57	12.15	4.24	0.86
AABSA1	-.31	29.55	4.73	29.41	8.01	36.66	9.86	0.18
AABSA2	-.23	36.18	9.47	31.78	8.29	30.52	6.69	0.40
AABSB1	-.39*	15.66	18.23	8.07	4.78	7.91	4.74	0.23
AABSB2	-.34	13.98	6.21	10.64	4.82	10.01	5.08	0.33
ALOA1	.39*	8.48	2.93	8.12	4.25	13.90	17.78	0.07
ALOA2	-.15	9.78	8.37	12.07	5.46	6.51	3.22	0.19
ALOB1	-.47*	12.05	14.18	5.95	4.38	3.47	4.50	0.13
ALOB2	-.53*	14.30	11.15	7.34	3.51	4.77	2.19	0.01*
ALNAI	-.02	2.71	1.96	2.90	1.34	2.68	0.82	0.93
ALNA2	.09	2.7l	1.15	2.33	1.46	2.87	1.34	0.67
ALNB1	-.04	5.65	4.00	6.85	4.17	5.68	3.79	0.72
ALNB2	-.02	6.41	4.56	5.86	5.37	6.90	4.98	0.90
ASKHA1	-.31	14.60	3.48	13.94	7.26	8.50	9.04	0.26
ASKHA2	.16	10.80	4.46	10.99	6.16	12.52	5.23	0.80
ASKHB1	-.21	5.15	6.19	3.36	2.65	3.87	2.36	0.61
ASKHB2	-.11	5.15	4.00	3.78	2.42	4.27	2.50	0.60

In the above-average group of ski jumpers, the vertical speed (VTTY) in the flight phase was, in the first part of the flight, similar to that of the average and below-average group. Larger differences occurred at the point 78 m away from the edge of the jumping-off platform where in the below-average group of ski jumpers the speed increased by 0.5 m/s on average. It is certain that in the continuation of flight these differences became even larger, and considerably influenced the length of the jump. The vertical speed component thus increased the angle of elevation (ALE) for which the results showed that in the middle part of the flight it was the statistically most important discriminating factor of the quality between the individual groups of ski jumpers.

The results of the research thus completely agree with the theoretical definitions of the technique of ski jumping (Vaverka, 1987). During flight the ski jumper must maximise the horizontal speed of the flight and minimise the vertical speed of the flight. Therefore, the ski jumper must minimise air resistance in the horizontal direction and friction already in the support phase of the take-off, and at the same time maximise the vertical speed of the take-off (Jošt, 1993), by which he will be able to raise the movement trajectory of the body's centre of gravity in the phase of take-off. In a three-year observation of the best ski jumpers in the world, Vaverka and Janura (1994/1992-94), established, at the competitions held in Innsbruck, characteristic differences in the take-off phase (5.6 m after leaving the edge of the jumping-off platform) between the different quality groups of ski jumpers. In the best ski jumpers, this angle amounted to 7.4 on average, while in the average competitors it was 6.6, and in the below-average 5.6 degrees.

In general, the tendency to the highest possible flight path of the body's centre of gravity is also preserved in the middle part of the flight (Jošt, 1994A), when the ski jumper must minimise the angle between the horizontal speed and the resultant speed of the trajectory of movement of the body's centre of gravity.

From the aspect of the defined speeds and the angle of elevation, such tendencies can be reached by ski jumpers (Hiroshi et. al., 1995; Jošt, 1994A), who in the flight itself lean more forward and have a smaller angle between the axis of the body and the skis. In flight, the skis should be placed as horizontally as possible or slightly above the horizontal. In this way, the aerodynamic resistance in the horizontal direction is minimised, while the aerodynamic thrust is increased at the same time. These theoretical assumptions (Vaverka, 1987) also agree with the findings of this research. In the angle (ASAS) which indicates the inclination of the axis of the ski jumper's body in the forward direction relative to the horizontal we can establish the tendency of minimising the said angle. In this way the ski jumper minimises air resistance in the horizontal direction and maximises the effects of aerodynamic thrust and air resistance in the vertical direction.

In the angle (AABS) which indicates the inclination between the longitudinal axis of the ski jumper's body and the skis, we established the tendency of minimising the said angle. However, we should be very careful as this logic is very relative. Namely, it is conditioned by the angle between the longitudinal axis of the body of the ski jumper and the horizontal axis (ASAS). This in turn means that the minimisation of the said angle is conditioned by the reduction of the ASAS angle. Ski jumpers that lean more in the forward direction in the air will achieve a smaller ASAS angle. However, if a ski jumper is more inclined in the backward direction, he has to increase the ASAS angle, otherwise he would increase the negative influences of the air resistance acting in both the directions even more, and in this connection also of the aerodynamic thrust, which would then hypothetically actually collapse due to the increase of the angle of incidence. From the aspect of performance success of a ski jump it is certainly desirable to optimise the ASAS angle towards lower values. This fact is even more confirmed by the angle between the longitudinal axis of the top part of the body and the skis (ALO). There is a pronounced tendency of minimising of the ALO angle which as a consequence means a better utilisation of aerodynamic effects both from the aspect of air resistance and aerodynamic thrust. This tendency is pronounced in particular in the middle part of flight where these differences between the above-average and the below-average group were larger. The above-average group had an average value of the ALO angle between 3.47 and 4.98, and the below-average group between 12.05 and 14.30 degrees. The differences between quality groups were statistically significant.

With the breakthrough of the new "V" technique, particular attention is paid to the position and function of the skis during flight. The results of this research point to the characteristic differences between the worse and better ski jumpers in particular in the middle part of flight. Better ski jumpers had, on average, a larger setting angle between the skis (ASKI) during the first part of the flight. The differences increased to the point where the position of the skis was assessed, i.e. 78 m after leaving the edge of the jumping-off platform, so that in the second jump they were already statistically significant and amounted to 8 degrees on average.

The position of the skis during flight is a very important factor of the performance of a ski jumper. In addition to the requirement for the optimal opening of the skis into the "V" position and longitudinal rotation of the skis (hypothetically maximally up to 20 degrees), this research has also confirmed the theoretical assumption on the minimisation of the angle (ASKH) which indicates the relationship between the longitudinal axis of the skis and the horizontal axis. Skis that are set more in the direction of the horizontal will cause less air resistance and a smaller twisting moment in the bindings. As a result of this, the ski jumper has, in addition to better aerodynamic effects, also a better feeling of stability of the skis and hence also of safety.

Researchers paid particulary attention to the angle at the hip (HIP). In this research this angle was considerably lower in the first part of flight (on average 146 degrees) than in the middle part of flight (on average 172 degrees). In the first jump there was a statistically relevant difference between the below-average and above-average group of ski jumpers which points to the tendency towards the optimisation of this angle in the direction towards larger values. In all probability, this tendency was observed during the period of the old technique as Jošt (1994A) established - in studying the best ski jumpers of the world at Planica, K120 - a considerably higher average value (164 degrees) than the researchers before him (Nagorny (1955), 150 degrees; Hochmuth (1985), 130 degrees; Tani-Iuchi (1971), 158 degrees; Baumann (1978), 130 degrees - 150 degrees and 10 better jumps 150 degrees - the data were taken according to Vaverka, 1987). This tendency has its meaning in terms of improvement of the aerodynamic conditions for the flight. In this way the ski jumper minimises air resistance in the horizontal direction and at the same time maximises it in the vertical direction. At the same time, he, of course, also achieves a better utilisation of aerodynamic thrust. The positive tendency of extending the body at the hips is in high correlation with the findings of the experimental studies of the "V-style" in the wind tunnel. As found by Hiroshi and his collaborators (1995), the optimal position of a ski jumper in the middle and final phase of flight is the so-called "Flat V-style". For this position, high extension at the hips and longitudinal levelling of the skis with the body are characteristic. Here it is, of course, necessary to take into account the setting angle of the body-skis system relative to the angle of flying. In the case of a poor setting angle, the said position will have very large negative aerodynamic moments. Due to that, the ski jumper must have the smallest possible setting angle, which has also been proved by the outcomes of the present research.

The position of the arms in the air is very variable and unpredictable. With respect to the statistical significance of the angle (AABV) in the first part of the flight we could presume the tendency of minimising this angle. The position of the arms depends on a multitude of factors which balance the equilibrium moments during flight. The arms serve as a kind of "flaps" with which the ski jumper adjusts the entire body in the air. In the middle part of flight, and above all in the final part of flight, the tendency of minimising this angle is obvious.

The position of the arms expressed by the angle (AABH) also confirms the tendency of optimising this position in the direction of smaller values. Better ski jumpers had on average smaller values of this angle both in the first and in the middle part of flight, in which, however, the average value in general increased significantly in all ski jumpers. This movement in terms of moving the arms away from the body in all probability enables the ski jumper to stabilise the ski jumper skis system in the air better and to prevent any possible longitudinal rotations of this system. It is obvious that better ski jumpers achieve this stabilisation by a smaller average movement of the arms away from the body.

Conclusion

On the basis of the results of the research carried out on a sample of 28 best ski jumpers, the participants in the World Championship in ski flights at Planica in 1994, we could at least hypothetically define the following kinematic tendencies of a successfully performed jump:

- to maximise the resultant speed of the movement of the body's centre of gravity in the first part of flight (VTT);
- to maximise the speed of movement of the body's centre of gravity in the horizontal direction (VTTX) during the entire time of the flight and in particular in the first part of the flight;
- to reduce the angle between the longitudinal axis of the body of the ski jumper (=axis of the body) and the horizontal (ASAS), above all in the middle part of the flight;
- to reduce the angle between the longitudinal axis of the body of the ski jumper and the skis in all parts of the flight path (ALF);
- to minimise the angle of elevation of flight (ALE) in the middle part of flight and
- to optimise the angle between the longitudinal axis of the upper part of the body and the skis (ALO) in the take-off phase, and to minimise it in the middle part of flight. Here this requirement is combined with the requirement for the minimisation of the angle between the skis and the horizontal (ASKH).

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