A KINEMATIC ANALYSIS OF THE V-STYLE SKI JUMP

BY

CHEN SHAO-MING ©

A THESIS SUBMITTED TO THE OFFICE OF THE GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SPORT SCIENCE IN APPLIED SPORT SCIENCE AND COACHING

SCHOOL OF PHYSICAL EDUCATION AND ATHLETICS

LAKEHEAD UNIVERSITY

THUNDER BAY, ONTARIO

ISBN 0-315-97038-3

Abstract

The purpose of the study was to identify, describe, and quantify selected kinematic variables associated with the successful performance of the ski jump. Secondly, this study attempted to determine the statistical contribution of specific kinematic variables at take-off and the beginning of the transition phase for the distance jumped.

The subjects for this investigation were 60 highly skilled competitors participating in 1994 World Cup K-120 event. The top twenty eight jumpers were selected from the first and second jump of the official training day for the K-120 event.

Data were collected using two Panasonic video cameras, one was set up to record the take-off phase, another was set to record the transition phase, equipped with a high speed shutter. Data for the distance jumped were collected from the records for the two official training jumps held the first day of official competition.

The 2D Peak Performance Video Analysis System was used

to extract the horizontal and vertical coordinates for a 23 segment model. The centre of mass was calculated by a model which included 14 body segments. The data were smoothed using a second order Butterworth digital filter and processed to compute measures for determining linear displacements and velocities and angular displacements and angular velocity values. A computer program written by the author was used to process the data calculated for the variables selected specifically for analysis in this study.

A correlation analysis was conducted to determine the existence and strength of any relationships between the selected variables and distance jumped. Seven variables were included in the multiple regression analyses. A full regression model provided the relative contribution of each predictor variable to the distance jumped. A stepwise regression model eliminated those variables which did not contribute significantly to the regression.

Based on the results of the study, selected kinematic variables associated with the distance jumped were identified and described. The similarities and difference between the traditional style and the V-style of jumping were discussed. The results suggested that the jumpers who want to increase the distance should generate as large as possible in-run speed, create an optimal aerodynamic body position with forward lean movement, take a quicker drive segment extension to begin a forward lean rotation, at the same time keep and increase continually the velocity in the take-off phase, keep and increase the forward lean movement of body and extension in order to create an optimum aerodynamic body position during the transition phase.

TABLE OF CONTENTS

LIST OF TABLES.................................. vi
LIST OF FIGURES vii

INTRODUCTION.................................... 1

Statement of Purpose 2
Limitation 3
Delimitation 3
Research Hypotheses 4
Definition of Terms 5

LITERATURE REVIEW 7

In-run Phase 7
Take-off Phase 10
Flight Phase 18
Landing Phase 21
V-style of Ski Jumps............................ 21
Applied Research and Testing of
Elite Jumpers 22
Summary 28

EXPERIMENTAL PROCEDURES......................... 31

Preliminary Investigation....................... 31
General Procedures.............................. 32
Video-taping Procedures......................... 33
Determination of Distance Jumped................ 35
Data Analyses................................... 35
Variable Selection 39
Data Smoothing.................................. 45
Statistical Procedure........................... 46

RESULTS... 48

Measurement Reliability......................... 48
Relationships Between Selected Variables
and Distance Jumped 49
Relationships Among the Selected
Independent Variables 57
Multiple Regression Analysis 59

DISCUSSION 63

Descriptive Analysis 63
Correlation Analysis 73
Regression Analysis 75
Similarities and Difference between the Traditional Style of Jumping and the V Style 77

SUMMARY, FINDING, CONCLUSIONS AND RECOMMENDATIONS 82

Summary 82
Findings 84
Conclusions 87
Recommendations 89

REFERENCES 90

APPENDICES 94

Mean Performance Measures on All Variables 95
COMPUTER PROGRAM 100

LIST OF TABLES

TABLE

1. Subjects 34

2. Intraclass Reliability Coefficients for Location of Segmental Endpoints 49

3. Correlation Between Selected Independent Variables and Dependent Variable Distance Jumped 55

4. Regression to Predict Distance from Selected Variables 61

5. Stepwise Regression to Predict Distance from Selected Variables 62

LIST OF FIGURES

FIGURE: Page

1. Phases of the Ski Jump 8
2. Proper In-run Position 11
3. Position at the Beginning of Take-off and Segment Angles Analyzed 13
4. Flight Position and the Segment Angles Analyzed 15
5. Set up of Video Cameras 36
6. The spatial model of ski jumping . 38
7. Take-off Angle.................... 44
8. The Frames during Take-off Phase for Top 6 Jumpers 64
9. The Frames during Transition Phase for Top 6 Jumpers 69

ACKNOWLEDGEMENT

The author would like to express his sincere gratitude to the following people who assisted in this thesis effort.

First and most important appreciation to Dr. Moira Mcpherson, this study could not have been completed without her friendship, scholarly advice, encouragement, endless discussion and correction. The author also would like to express his sincere appreciation to Dr. Moira Mcpherson for her guidance and enthusiasm throughout his graduate studies. Appreciation is also extended to professor Dr. Tony Bauer and Dr. Frantisvek Vaverka for their advice regarding the conduct and writing of this thesis. Appreciation is also extended to Mr. Mark Thomas for his assistance during the collection of data.

A sincere thank you is also extended to Ski Jumping Canada and the Big Thunder National Training Centre for their financial support and cooperation in the collection of data.

Chen Shao-ming

INTRODUCTION

The ski jump is typically divided into 4 phases; the in-run, the take off, the flight, and the landing phase (Pulli, 1989; Vaverka, 1991). In the competitive situation a ski jumper is awarded points based on the distance jumped and the form. Flight and landing form are subjectively evaluated by judges. Points based on the position of the jumper's feet at the instant of landing are determined relative to the critical point of the hill. A very complex camera and projection system has been used in recent world cup events to provide an objective measure of this length.

Over the past two decades, film analysis, force measurement, EMG analysis and wind tunnel experiments have been conducted by scientists attempting to investigate the factors related to the successful performance of the ski jump. However, there are very few reports of studies which have been completed during either winter training or competitive situations. Furthermore conclusions reported in the literature vary among the researchers due to the application of different theoretical models and limited methodologies (Gisler, 1974; Komi, 1974; Nigg, 1977; Pulli, 1989).

It is widely recognized that the length of flight is substantially influenced by the skier's position in the air and by the change of orientation of this position relative to the external forces during the flight (Remizov, 1984). The aerodynamic characteristics of the jumper/ski system as a function of the parameters of take off have not been reported. Based on the literature, it is extremely difficult to determine the contribution of the flight phase to the distance jumped. It is apparent that there is a relationship between the movements during take-off and in the transition into flight. However, many questions remain unanswered.

There is a need to investigate ski jumping using kinematic measurement and analysis techniques during competitive jumping events.

Statement of Purpose

Purpose

The purpose of this study was first to identify and quantify the linear and angular movements of the segments and the whole body during the take-off and transition into flight of the V-Style ski jump. In addition, this study also attempted to determine the statistical contribution of specific kinematic variables to the distance jumped by world class ski jumpers.

Limitations

The study was limited by the following factors:

1. The accuracy and reliability of the researcher in digitizing the anatomical endpoints of the body segments.

2. The influence of temperature, humidity and wind on the analysis instruments used during the field taping.

3. Limitations in the method of measurement used to determine the instants of beginning and end of the take-off area.

4. The limitations imposed on the analysis by the camera sampling rate.

Delimitations

The investigation was delimited to:

1. The data collected on ski jumps performed by 60 competitors participating in the 1994 World Cup

event held on March 25, 1994 in Thunder Bay, Canada.

2. The analysis of recordings made using two video cameras set up to record movements in the sagittal plane of motion for the take-off phase and transition into flight phase.

3. The relationship between specific parameters at take-off and initial flight and the distance of the jump as recorded by the competition officials.

4. The analysis of the following variables: linear displacements, velocities, accelerations, angular displacements, and velocities as well as the path of centre of mass during the take-off and transition phase into flight.

Research Hypothesis

The hypotheses were :

1. There is a relationship between the dependent variable, the official distance which was recorded for each jump, and the independent variables (position of centre of mass, in-run speed, take-off velocity, the angle of takeoff velocity, the angle of shoulder, elbow, knee, trunk, leg, and the angular velocity of shoulder, elbow, knee, trunk, ski, leg and the centre

of mass in the take-off and transition flight phases).

2. There are relationships among selected independent kinematic variables.

3. There is an order to the relative importance of each of the selected independent variables in predicting the dependent variable.

Definition Of Terms

In-run phase

The in-run phase begins when the jumper leaves the start gate and proceeds until he begins to lift his centre of mass for the preparation of takeoff. The purpose of this phase is to generate maximum approach velocity prior to takeoff.

Take-off Phase

The takeoff phase begins when the jumper begins to lift his centre of mass to prepare for takeoff, the phase is completed when the skis are completely lifted off the snow.

Transition phase

The transition phase begins the instant that the ski is completely lifted off the snow at take-off and continues to the point where the knee has a maximum extension angle and the skis are positioned in the V position. The area for taping in this study is seven meters which begins one meter before the edge of platform and ends at 6 meters after the edge of platform.

Flight Phase and Flight Time

The flight phase begins when the V position is assumed and ends the instant that the landing ski makes contact with the snow again. The flight time is defined as the period from the instant of takeoff to the instant of landing.

Landing Phase

The landing phase begins the instant the ski makes contact with the snow. The phase is completed once the skier has assumed a dynamic upright position.

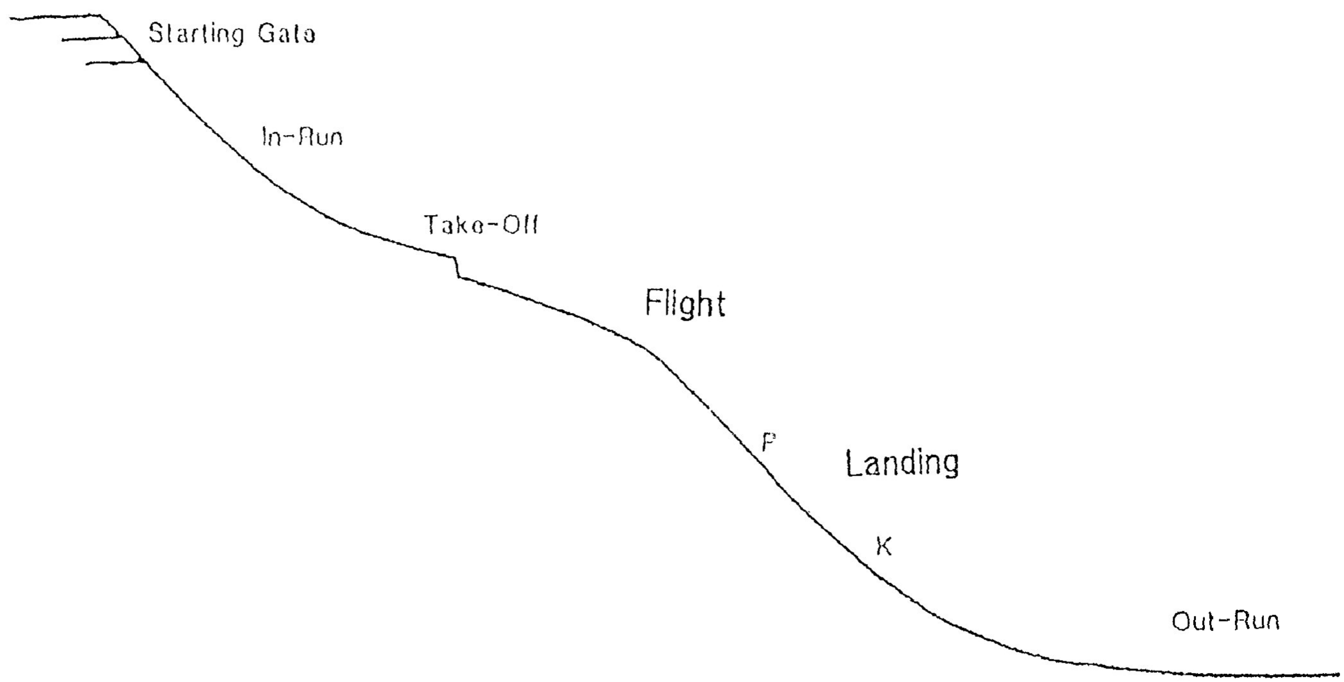
LITERATURE REVIEW

Ski jumping is a highly technical sport which requires precise timing and perfect technique execution at very fast speeds. Many other external and internal factors with respect to the jumper will also affect the outcome of the jump. As early as 1927, Strauman (1927) began biomechanical studies on ski jumping. Since then, many researchers have continued to study in both the laboratory and competition conditions. The general description of ski jumping as well as the critical technical factors have been discussed from many different view points. Several analytical methods have been used in biomechanical research: film-analysis or video analysis, force measurement, wind tunnels, and electromyographic analyses. In general, ski jumping is divided into four phases for biomechanical analysis: in-run, take-off, flight and landing (Figure 1). All of these phases are related to the length of the ski jump, but the most important factors are related to the takeoff and the flight.

In-Run Phase

The aim of the in-run in ski jumping is to

Figure 1. The phases of the ski jumping



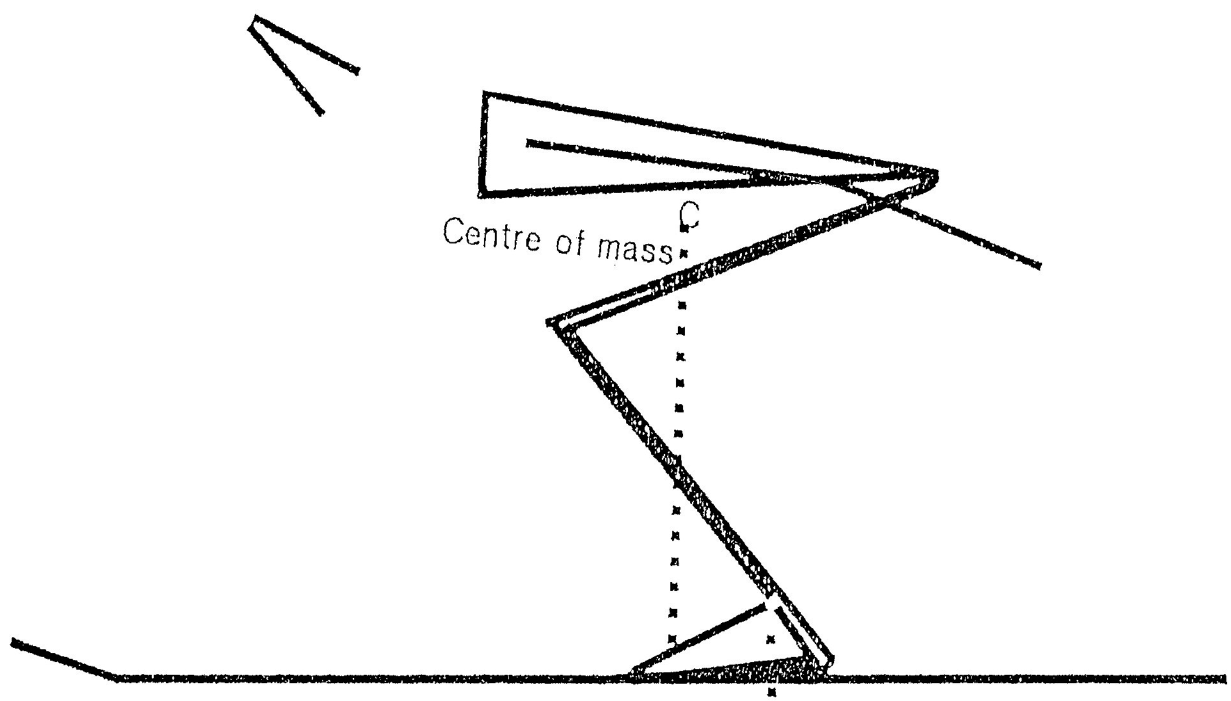
generate maximum velocity over a standard distance. The purpose is to convert the potential energy of the jumper's mass into kinetic energy from the top of the jump to the end of the in-run. During this phase, there is an energy loss caused by the friction and air resistance (Campbell, 1990; Pulli, 1989). A jumper can generate an initial velocity of 4 m/s with a powerful start. Under optimum conditions, the initial velocity may exceed the final velocity by 0.3-0.4 m/s (Grison, 1971). With the above preconditions, the length of jump on a 70 m ski jump may be increased by 3-5 meters (Reichert, 1980). The force which contributes to an increase in velocity during the in-run is the gravity (tangential component). Researchers have found that the mass, or weight of a skier is not the main factor on which the speed of the straight descent depends. The velocity is most sensitive to aerodynamic forces, or air resistance during the same period. The aerodynamic forces are related to the position of the skier. Campbell (1990) reported that the proper position has been estimated through wind tunnel tests and mathematic studies: "the back should be flat and parallel to the skis with the feet 4 to 6 inches apart and the legs upright. The arms are positioned back along the trunk, parallel to the skis. Small changes in arm position may cause drag differences up to 20 percent. This is especially important in the last 25 meters of the approach when velocity is above 20 m/s (p.316) (See Figure 2)".

Take-Off Phase

Strauman (1957), Pulli (1989), Virmavirta (1989) and Campbell (1990) stressed that the take-off phase has the most significant effect on the length of flight.

Campbell (1990) stated that the objectives of the take-off were to generate a maximum vertical velocity, to produce a favourable body position at the jump's edge, and to provide an initial turning moment for the forward rotation of the body over the skis immediately after take-off. This should be accomplished without significantly decreasing the tangential velocity. He reported that results from the biomechanical analyses of the 1979 pre-Olympic jumping event indicated that the position of the centre of mass relative to the base of support, the angle of the lower leg, the normal

Figure 2. The Proper in-run position

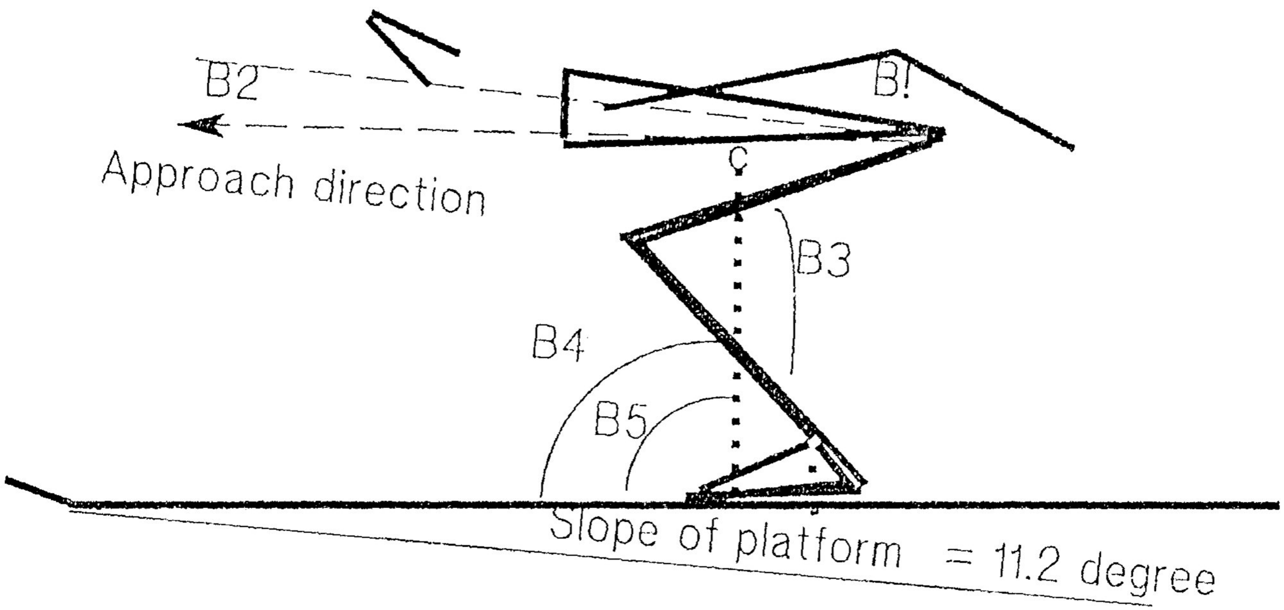


acceleration and velocity, the take-off angle, and the angular velocity at the hip and knee joints were all significantly related to the length of jump and stated that the problems encountered during take-off can be considered as existing in two areas. The first area relates to the positioning of the skier during the movement. In the beginning of the take-off or thrusting movement, the centre of gravity is located slightly behind the ankle. The ability to create a larger forward turning moment dictates the amount of lift that can be generated by the trunk surface during preflight and still allows the jumper to move forward into a favourable flight position (See Figure 3).

The second area relates to the input from the skier in the jumping motion. This area includes strength, rate of movement, and sequencing and timing of the extension. The ability of a ski jumper to produce a velocity component which is normal or perpendicular to the ramp directly affects the distance jumped.

Pulli and Luhtanen (1989) indicated that there were two groups of factors which affect the length of ski jump. The first group, ballistic factors, focus on

Figure 3. Position at the beginning of take-off and the segment angles analyzed



B1___ Elbow angle

B2___ Trunk angle

B3___ Knee angle

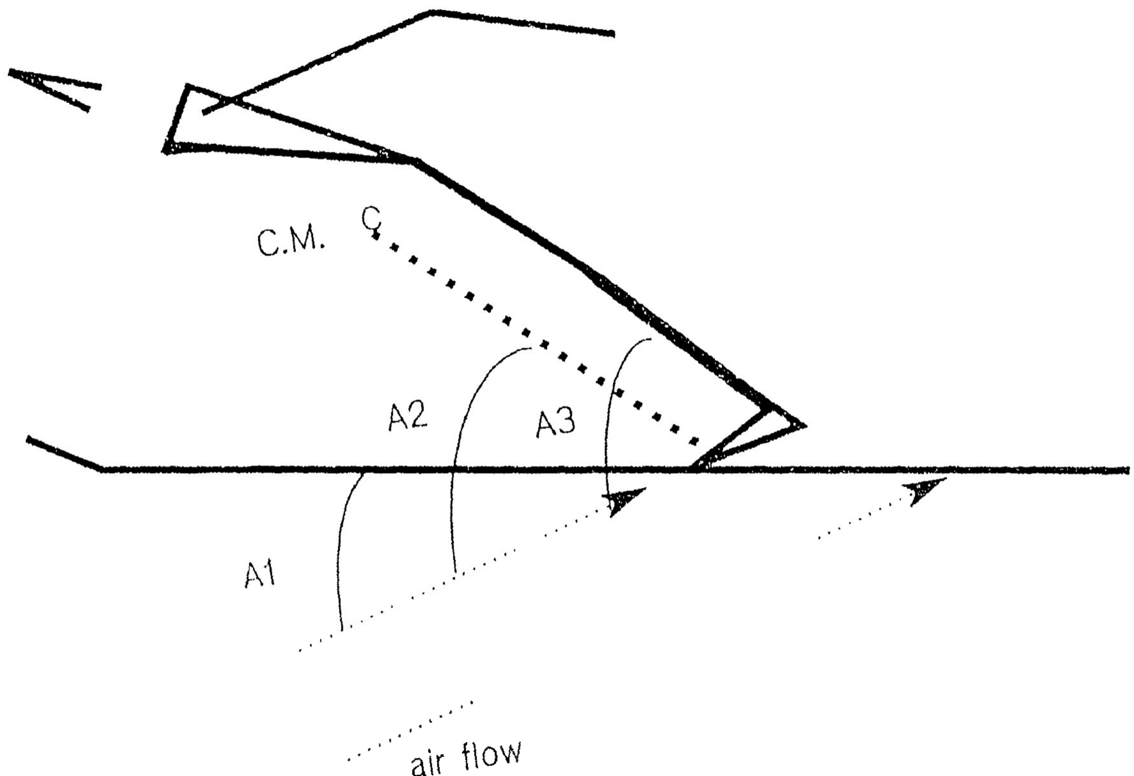
B4___ Leg angle

B5___C/M angle

the velocity generated by the jumper on the in-run and the angle at takeoff of the path of the centre of mass of the jumper relative to the jumping platform. Later, Pulli (1989) added that the height of the centre of mass at the instant of take-off was key to the success of the jump. The optimal jumper/ski position for flight has also been determined for stable conditions through wind tunnel tests and mathematical modelling. However in the competitive arena, ski jumping conditions are rarely stable and the ski jumper must make modifications in position to account for this. A number of researchers have reported that these modifications are only slight and the optimal position can be generally described based on the laboratory research (Campbell, 1990; Virmavirta, 1989) (See Figure 4).

Watanabe (1989) stated that the analysis of take-off motion should be divided into three aspects: timing (the sequence of take-off including both the whole body and body segments), spacing (take-off angle) and grading (the regulation of jumping power during take-off), and these factors relate to how this movement should be performed. Komi et al. (1974) pointed out that the better jumpers initiate the

Figure 4. Flight position and the segment angle analyzed



A1 – Ski angle

A2 – C/M angle

A3 – Leg angle

movement closer tothe edge of ramp, while completing the take-off in less time. Watanabe (1985) experimented with a simulated jump from different surface conditions (frictional coefficients of the surfaces ranged from 1.0 to 0.03) and compared the jump performance (distance) and power production on a Kistler force plate. He found that the subjects produced their maximum jump power at an angle of 85 degrees and values range from 80 degrees to a vertical jump because of the slippery conditions. There exists a very large gap between the take-off angle in actual conditions and on a simulated take-off. He also stated that an important objective was to generate vertical position of the body during take off, thus facilitating flight arch in the next phase. Pulli (1989) demonstrated the force measurement of the heel and toe on a 70 m jump hill using a telemetry system and found that during force production patterns of take-off, there was a shift of force from front of heel to toe in the take-off. They suggested that the coaching and training target should be focused on a reasonable aerodynamic position before take-off rather than paying too much attention to vertical acceleration. Sagesser et al.(1981) reported the result of a force measuring system for ski jump and found that a correlation between the jumping time and jump performance was produced and the best jump of each subject had a take-off time between 40 and 43 msec. By contrast, others (Pulli, 1989) have considered it more important to find a way in which to have the jumper change the aerodynamic position before take-off to an aerodynamic position after take-off as quickly as possible and with the least air resistance possible.

Strauman (1957) indicated that the most important point at take off was to maintain the velocity generated on the in-run and to produce a position as advantageous to the flight as possible. Hochmuth (1958) stated that a change of 1 m/s in velocity on the jumping platform for a 70 ski jump would affect the length of jump by 4-9 meters, elevating the path of the centre of gravity by 3 meters at a jumping velocity of 23 m/s would increase the length of jump between 9-14 meters. Baumann (1978) emphasized the importance of the timing of the take-off action to the resulting jump.

Ruegg and Troxler (1979) stated that the force, impulse, and time parameters were indicative of good jumpers at takeoff, and that there was a significant correlation between the length of the jump and the force produced during the takeoff. According to Pulli (1989):

> the aerodynamic characteristics of the jumper/ski system is best represented by the ratio L/D where L is the lift and D is the drag on the forehead. This ratio may exceed the value of 1 i.e. the lift is greater than the drag (p. 365).

Pulli (1989) indicated that the jumper had to keep the velocity generated in the in-run, to elevate the path of his centre of mass at take-off, to move the jumper-ski system in a short period of time in order to get a favourable position for flight and a correct moment for the duration of the flight, and to maximize the length of the jump. The conditions of take-off is complex and no unambiguous theoretical model has been found so far.

Flight Phase

The purpose of the flight is to obtain the most favourable, or aerodynamically efficient jumper-ski position. Pulli (1989) reported that the flight characteristics of the jumper-ski system had been studied in several wind tunnel experiments (Strauman, 1927; Tani & Iuchi, 1971; Watanabe, 1985). He also pointed out at the same time that changes in the flight position were easily reflected in the length of a jump. In general, the body should be kept bent forward, (See Figure 4) the arm should be kept extended backward to achieve a better performance in order to generate a large lift: drag ratio in order to maximize flight distance (Watanabe, 1989). As mentioned above, Pulli and Luhtanen (1980) indicated that the second group of factors which affect the length of ski jump, aerodynamic factors, focus on all of the flight characteristics of the jumper-ski system in the air. While it is widely recognized that the length of the flight is substantially influenced by the skier's position in the air and by the change of orientation of this position relative to the external forces, the aerodynamic characteristics of the jumper-ski system as a function of the parameters of take-off are difficult to analyze and have not been reported (Remizov, 1984). Another study by Watanabe (1972) examined the flight posture by using electromyography (EMG) techniques during an actual jumping situation. The EMG activity for the tibialis anterior muscle showed that the skilled jumpers were able to keep their skis in a relatively constant position just before landing. Pulli (1989) stated that the position of the arms close to the body provided the optimal lift to drag ratio (L/D). The hand (palm) should be positioned at a right angle against the air stream for the best performance. It has been found that the optimal jumper-ski orientation for producing maximum distance in stable conditions was dictated by four angles: the angle of attack (the angle between the skis and airflow); the forward lean angle (measured as the angle between the legs and skis); the trunk bend angle(angle between the extension of a line through the legs and the trunk); and the optimal arm angle (the angle between the trunk and arm). The optimum flight position has also been suggested by Hochmuth (1958), Tani & Iuchi (1971) Baumann (1978). Baumann (1978) pointed out that an "egg- shaped" position produces 50% less air resistance than the "half- standing" position.

Landing Phase

For the landing analysis, Pulli (1989) stated that the difficulty of landing depended mainly on the angular velocity in the air, angle of landing and the position of the body relative to the landing slope. The resultant of the external forces generated at landing that determine the direction of motion of the centre of mass can easily be overcome by the muscle forces.

V-Style of Ski Jumps

Over the past decade the V-style of jumping has been attempted with varying degrees of success by jumpers performing in international competitions. However, until very recently, the style received little attention. During 1992 competitions, a young Finnish skier won four World Cup events and far out jumped the rest of the field using the V-style of jump. The vast majority of the best jumpers in the world have now also adapted the style and in most cases are attaining greater flight distance. The in-run movement of jumpers using the V-Style technique is the same as the in-run movements involved in the traditional technique. The main difference between the V-Style and traditional style of jump occur during the tradition into flight and flight phase. During performance of the v-Style, jumpers must separate their legs into a V style position while rotating the body forward over the skis. Both styles of ski jump technique utilize the telemark landing. Over the past two decades there have been numerous experiments conducted by scientists attempting to investigate the factors related to the successful performance of the Classic style ski jump. The mechanics as they related to the new V-style of jumping have not been studied during competition and are not well understood.

Applied Research and Testing of Elite Jumpers

There has been ongoing biomechanical research focused on ski-jumping for many years, but most work has been done under the conditions of simulation in the laboratory. Until the 1980's, when modern data analysis techniques were developed, few researchers conducted biomechanical studies during actual competition situations.

Campbell (1979) completed a biomechanical study of the take-off at the 1979 Pre-Olympic games at Lake

Placid with kinematic and dynamographic analyses and found that the following performance variables measured during the take-off phase were related to the distance jumped: position of the centre of mass relative to the base of support; the angle of the lower leg; normal acceleration and velocity; take-off angle, and the angular velocity at hip and knee joints.

Virmavirta and Komi (1988) measured the take-off force of jumpers with four force plates installed under the snow of the take-off platform used for the 1988 Winter Olympics in Calgary and reported that the greatest force was already exerted 149 ± 9 ms before the take-off. The second force peak appeared closer to the edge of the platform. He suggested that the fast development of the take-off force might be an important pre-requisite for successful ski jumping performance.

Dr. Frantisvek Vaverka of the Czech Republic is one individual who has completed extensive applied research over the past fifteen years and has made much progress on the systematic analysis of ski jumping. Vaverka (1990) described a system designed specifically for the analysis and training of ski jumping. The system includes three major parts:

1. A video analysis system
2. Automatic Ski-Jumping Measurement system
3. Force Measurement-Dynamometric system

The video analysis system was composed of a high-speed shutter video camera, a computer and a set of analysis software. The system provides various levels of information. For instance, the output of the analysis on the take-off phase were presented in various forms: a graphically expressed model of an athlete in the form of time lapsed stick figures; the position of the jumper is accented at a distance of every 1 m in the analysis; and a number of angles expressed in degrees describing the position of the body's segments in selected phases of the movement. Mathematical analysis of the curves provide detailed information about the changes of angle and speed in relation to time.

The Automatic Ski-Jumping Measurement System is an electromagnetic measurement system which is composed of a grid in the in-run phase and the landing phase, an amplifier in the in-run phase and the landing phase, a computer PC-AT, measurement software and the elaborating software. This system can measure the length of jump, the athlete's speed in the in-run phase and the landing phase. The whole system is controlled by computer and measured data are automatically stored in the memory. Specialised software in this system allows for a variety of statistical methods to be applied to the measured data.

The force measurement system is composed of a conventional force platform installed under the plastic of the jumping track to obtain take-off dynamometry during the final 6 m from the edge of take-off area. Output includes numerical data from force-time curves, the velocity of centre of mass of the competitor (and his equipment) during the last 6 m of the take-off, and distance from the take-off platform edge to the point where take-off was finished as an indication of take-off accuracy.

Vaverka (1991) also applied the results of measurement and analysis to model the take-off phase according to the following information: the distance from the edge of the take-off table, the time of the movement of the athletes with regards to the edge of take-off table, and the defined values of selected angles. Vaverka (1991) stated that the modelling process enables rapid computing of all other observed variables based on the choice of one independent variable. The described interactive method of modelling enables trainers and researchers to explore many possibilities for a variety of technical problems.

In 1991, Vaverka reported on a biomechanical examination of ski-jumping using the above system. He found that the consistency of the movement of ski-jumpers could be evaluated on the basis of correlation coefficients. The relationship between biomechanical parameters and the distance jumped was discussed in this study. He pointed out that the in-run velocity was a very important factor related to the distance jumped and the biomechanical parameters. The relationship between the explosive strength of the lower extremity and the take-off parameters and the distance jumped were difficult to obtain by simple -factor discussion. A "multi-factors theory of take-off" should be used in future research. Vaverka also gave an application of a statistical analyses method (T-method) to derive the optimum model which can be characterised in the following way:

1. The in-run velocity that the best jumper

achieved was slightly larger than the average of all participants who have similar technique characteristics.

2. Top performances in ski-jumping depend on a very high level of technique in the take-off and flight phase.

3. Increasing the in-run velocity significantly influences the distance which is jumped.

4. The in-run velocity of the best jumpers is only slightly above average of the whole set(Vaverka, 1991).

Vaverka has studied the national teams of several countries including Canada during competitions at Frenstat in 1990. He found that the in-run velocity of the Canadians were higher than the velocity of the best ski-jumpers; the quality of the technique of take-off and flight of the Canadian team was below the average of the whole set of jumpers, but two jumpers (Bulau, Capel) in the second round reached a slightly above average level of technique as compared to the best jumpers. He suggested that more detailed analyses of the in-run position of Canadian jumpers should be done in the future to help promote better performances.

Summary

Research which has focused on the mechanics of ski jumping has been conducted for many years. There are some commonalities found in the review of literature. For instance, the jump is divided into four phases, in-run, take-off, flight, landing. The most important factors are the movements of take-off and flight.

1. The velocity of take-off obtained from the in-run phase and the maximum velocity of centre of mass are determined by two factors: the powerful start at the beginning of the in-run and an optimal take-off position.

2. The objectives of the take-off are to generate a maximum vertical velocity, to produce a favourable body position, and to provide an initial turning moment for the forward rotation of the body as it moves into flight.

3. The factors that affect the distance jumped are ballistic factors (velocity, angle, height of the centre of mass, etc...) and aerodynamic factors (flight characteristics of the jumper/ski system).

4. The analysis of the take-off motion should include three aspects: timing, spacing and grading. The

most important point of the take-off phase is to maintain the velocity generated on the in-run and to produce a position as advantageous to the flight as possible. In order to consider how to find a way to change the aerodynamic position before take-off into an effective aerodynamic position after take-off, the force, impulse and time parameters of take-off should be considered.

5. In the flight phase, the purpose is to obtain the most favourable, or aerodynamically efficient position, thus, the trunk position, arm position and flight posture should be investigated.

The biomechanical studies on ski jumping during competitive events began in the 1980's. The video camera, force platforms and computer systems have all been used for research. Vaverka (1990, 1991, 1994), in particular, has made considerable progress in the systematic analysis of ski jumping using a system which is designed specifically for the analysis. Unfortunately, most of the dynamics research which has been conducted has focused on jumpers using plastic hills. The methodologies and technology associated with force measurement on snow covered tracks are very complex. There have been few reported scientific investigations which have focused on the new V-style of ski jumping. The purpose of this study is to examine the relationship between specific parameters of take-off and beginning of the transition into flight phase and the distance jumped by the world's best ski jumpers using the V-style during a world-cup competition.

EXPERIMENTAL PROCEDURES

The procedures used in the examination of the problem are described in the following sections:

1. Preliminary investigation
2. General procedures
3. Video-taping procedures
4. Length of jump determination
5. Data analyses
6. Data smoothing
7. Statistical procedures

Preliminary Investigation

A preliminary investigation was conducted on July, 1992 at the Big Thunder National Training Centre First Annual Plastic Jump competition. The investigation was undertaken to:

1. Determine the optimal positioning of the video camera at the takeoff initial flight.

2. Practice and refine the data collection and analysis procedures.

Data was collected for 27 National and Junior jumpers who completed one qualifying and two competition jumps on the 64 m hill. A Panasonic SVHS video camera equipped with a high speed shutter was used to tape the performances at an exposure rate equivalent to 60 frames/second. The camera was set with the high speed shutter at 1/4000 sec. All jumpers were taped as they passed through a targeted zone. The camera was levelled at a height of 1 meter and was positioned at a right angle to the zoned track and at a distance of approximately 15 meters. The data was smoothed and analyzed using the procedures outlined in the following sections.

General Procedures

Sample

The subjects in this study were 28 athletes who participated and ranked in the top 28 out of 40 on the first and second jumps on the official training day in 1994 World Cup K-120 event. All of the jumpers were males between the ages of 16 and 30 years.

Experiment protocol

The distances jumped of the each jumper were tabled and are presented in Table 1. As the data was collected during a competitive event, it was not possible to attain subject height and weight information.

Experimental Site

The experimental site was the National Training Centre at Big Thunder, Thunder Bay, Canada.

Wind Speed Recorded

For each jumper the wind speed was recorded by the competition officials. The mean value for the wind speed was 3.08 m/sec. The minimum and maximum scores were 0.0 and 7.00 m/sec. Values for the wind speed recorded during each jumper's performance are reported in Table 1.

Video-Taping Procedures

Data were collected by using two Panasonic video cameras (Type SVHS) equipped with a high speed shutter. The cameras recorded movement at a rate of 30 frames/second. The subsequent analysis procedure split each picture into two fields providing a sampling rate of 60 FPS. Both cameras were set with the high speed shutter at 1/1000. This was the optimal setting based on the available light. The cameras were levelled and positioned at a 90 degree angle to the plane of motion. All jumpers were filmed as they passed through the

Table 1

Subjects

THE BEST ATHLETES IN 120M OFFICIAL TRAINING

NO.	RANK	NAME	NAT	DIS. (m)	Wind (m/s)
Jump 1:					
30	1	A. Goldberger	AUT	134.5	3.1
18	2	L. Ottesen	NOR	132.0	2.2
9	3	N. Kazai	JPN	130.0	6.5
4	4	J. Lockyer	CAN	128.5	5.5
11	5	T. Okabe	JPN	127.5	0.0
35	6	W. Rathmayr	AUT	126.0	3.2
14	8	O. Berg	NOR	125.0	3.9
19	9	S. Tuff	NOR	121.5	0.0
28	11	S. Zupan	SUI	120.5	2.2
13	12	K. Suda	JPN	118.5	2.0
16	13	R. Ljokelsoy	NOR	118.0	7.0
12	14	H. Saitoh	JPN	118.0	0.0
23	18	R. Meglic	SLO	116.5	0.1
29	19	T. Langlois	USA	116.0	4.3
3	23	J. Blackburn	CAN	112.0	5.6
Jump 2:					
44	1	J. Soininen	FIN	128.5	5.2
43	2	A. Nikkola	FIN	127.5	2.3
42	3	T. Koponen	FIN	127.0	2.1
41	4	J. Ahonen	FIN	125.5	2.8
48	6	N. Dessum	FRA	123.0	4.1
45	7	J. Vaatainen	FIN	120.0	5.1
47	8	S. Delaup	FRA	116.5	4.3
32	11	S. Horngacher	AUT	110.5	0.0
5	14	R. Cecon	ITA	107.5	3.9
31	17	W. Haim	AUT	104.0	0.0
21	18	S. Gostisa	SLO	103.0	0.0
36	19	W. Schuster	AUT	102.5	2.6
38	19	Z. Krompolc	CZE	102.5	4.4

targeted zones. The first camera was located at 10 m from the take-off platform which allowed a field width of approximately seven m for take-off phase (six m behind and one m after platform. See Figure 5). The second camera was located at 25 m from the platform so as to record a side view of the beginning of the transition from take-off into flight phase. The field width of this view was seven m (one m before and six m after platform. See Figure 5). A diagram of the taping set-up is provided in Figure 5.

The data were collected from two official training jumps held the last day of official competition.

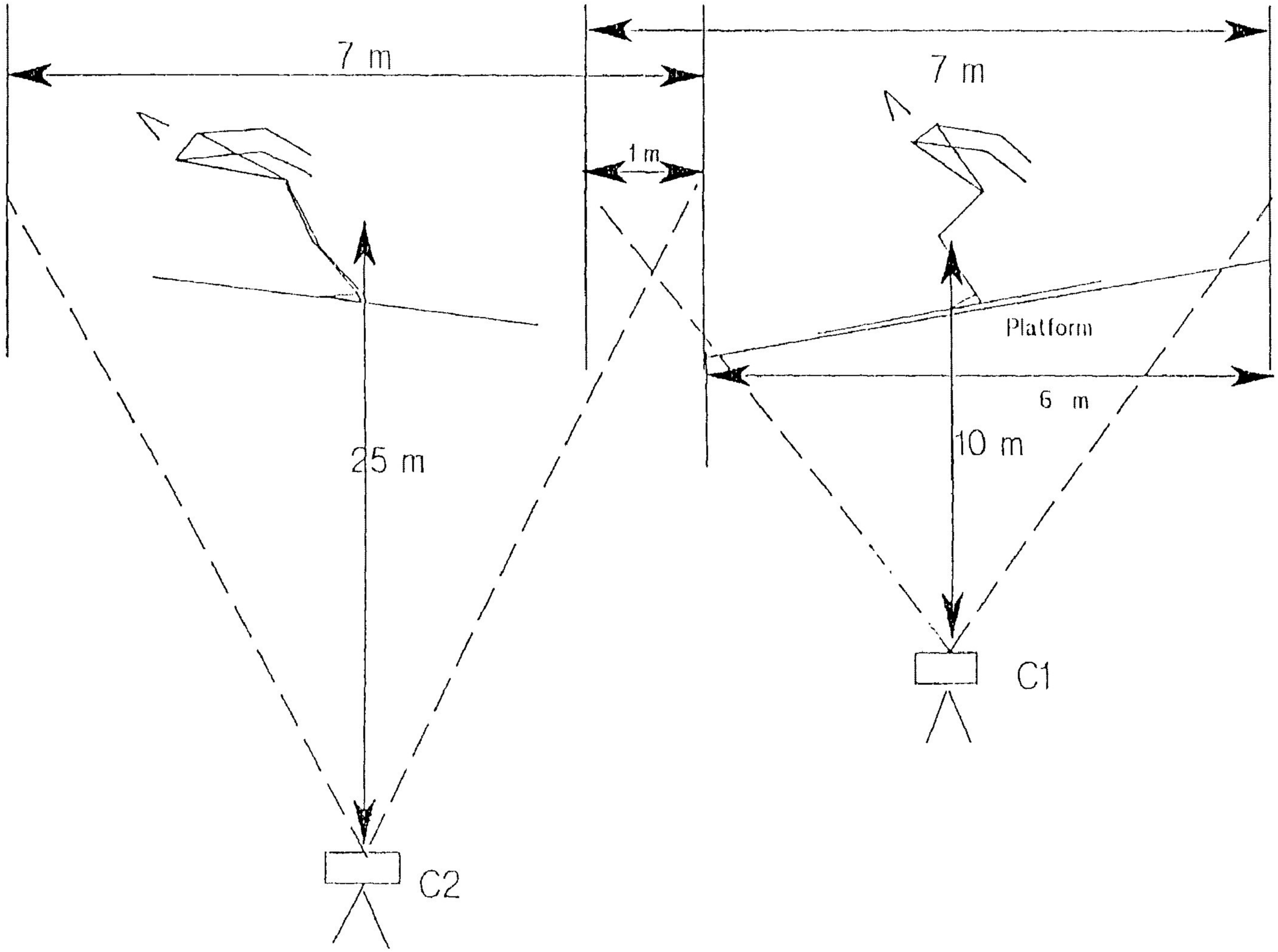
Determination of Distance Jumped

Data for each subject's length of jump were obtained from records measured by the competition officials and printed in the official results book.

Data Analysis

Each of the performances for the top 28 finishers in the first and second training jumps were digitized using the Peak Performance Video Analysis System located in the Biomechanics Laboratory at Lakehead

Figure 5. Set up of the video camera



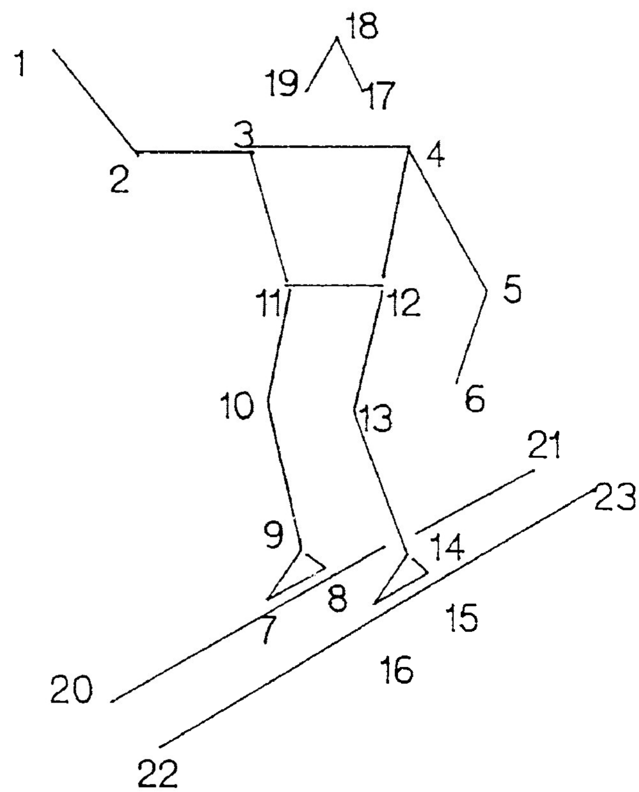
C1___Camera 1
C2___Camera 2

University. The data extracted from the taped records included the horizontal and vertical coordinates for a 23 segment model (see Figure 6) adapted to include skis. The data was smoothed using a second order Butterworth digital filter and processed to compute measures for the position of the centre of mass, the vertical velocity, the horizontal velocity, the resultant velocity at each frame of take-off and transition. Other measurements were the degree of flexion and extension for left shoulder, left elbow, left knee, trunk relative to approach direction, legs relative to approach direction, the angle of centre of mass relative to approach direction (the angle between the line connected to the toe and approach direction for each frame of the take-off), and trunk relative to the tangent of the flight curve, leg relative to the tangent of the flight curve, ski relative to the flight curve and the centre of mass relative to the tangent of the flight curve during the transition phase (refer to Figure 3). A computer program written by the author was used to process the data. This program cut off the first and last frames to increase the accuracy of the data and calculate the variables which were selected

Figure 6. The spatial model of ski jumping

LIST OF BODY POINTS

1. Right Wrist
2. Right Elbow
3. Right Shoulder
4. Left Shoulder
5. Left Elbow
6. Left Wrist
7. Right Toe
8. Right Heel
9. Right Ankle
10. Right Knee
11. Right Hip
12. Left Hip
13. Left Knee
14. Left Ankle
15. Left Heel
16. Left Toe
17. Left Ear
18. Top of Head
19. Right Ear
20. Right Ski Top
21 Right Ski End
22. Left Ski Top
23. Left Ski End



specifically for the study of ski jumping. The program enabled the researcher to customize the data analysis process. Output focused on each of the specific variables of interest. The results for each jumper's performance was plotted and compared.

Variable Selection

The variables selected for inclusion in the study were generated from a review of the literature and an attempt to initially consider a comprehensive description of the ski jump. The nine groups of variables selected for inclusion in the correlation analysis were as follows.

Centre of mass

The centre of mass was calculated by a model which includes 14 body segments using the 2D Peak Performance Analysis Program. The total body centre of mass did not include the mass of the skis due to an inability to measure the mass of the jumper's skis during the competition.

Critical Points

The movement of the take-off always happens over an area which includes both contact and non-contact phases. Three critical points were set as the reference points for describing the movements of the jumper during the take-off and transition phases:

B1 - A point was set at 6 meters before the edge of platform and defined as the beginning of the take-off phase. Each jumper was digitized as soon as they passed this point.

T1 - T1 was a point that was set at the edge of the platform to denote the end of the take-off contact phase.

E1 - The frame which marked the point of maximum lower extremity extension as identified by the maximum knee angle was used to define the end of the non-contact take-off phase.

The Position of Body

The horizontal and vertical coordinates of the centre of the system relative to the left ankle, the angle of the left shoulder, left elbow, left knee, trunk, leg and C/M relative to the approach direction were used to describe the position of the body at B1, T1.

The same variables mentioned above plus the angle of the skis were used to describe the position at T1 and E1 again for the discussion of the transition phase. The angles of the trunk, ski leg and C/M were defined relative to the tangent direction of the flight curve in order to compare the results to reports in the literature.

Distance

The horizontal and vertical distance from the frame which had the maximum knee angle to T1 was calculated during the take-off and transition phase respectively to find the point at which each jumper finished the take-off action.

Time

Two measures of time were calculated:

1. The total time of take-off and transition phase.

2. The time from the frame which had the maximum extension knee angle to T1.

Instantaneous Velocities of Centre of Mass

The instantaneous take-off velocity of the total body centre of mass in the approach, normal, resultant direction, were calculated at the instant of B1 and T1, critical points for the takeoff, and in the horizontal, vertical and resultant direction for the T1 and E1 critical points.

The velocities in the horizontal, vertical and resultant direction at the frame which had the maximum knee angle during the transition phase were also calculated.

<u>Average Velocities of Centre of Mass</u>

The three average velocities which were obtained for the analysis are:

1. In-run average velocity - In-run average velocity was the mean of the velocities during the last 6 meters of the in-run phase. This velocity was obtained from the official competition records.

2. Take-off average velocity - Take-off average velocity was the mean of the velocities during the take-off phase of the jump.

3. Transition average velocity - Transition average velocity was the mean of the velocities during the transition phase of the jump. This velocity and the take-off average velocity were calculated by a program written by the author.

<u>Angle of Take-Off of centre of mass</u>

The angle at which the centre of mass was projected into the air was calculated using the horizontal speed combined with the vertical speed at the instant of take-off (see Figure 7) using the formula:

QTT = ARCtan (Vv/Vh)

Where:

QTT = Angle of take-off.

Vv = Vertical velocity.

Vh = Horizontal Velocity.

Angular Displacement

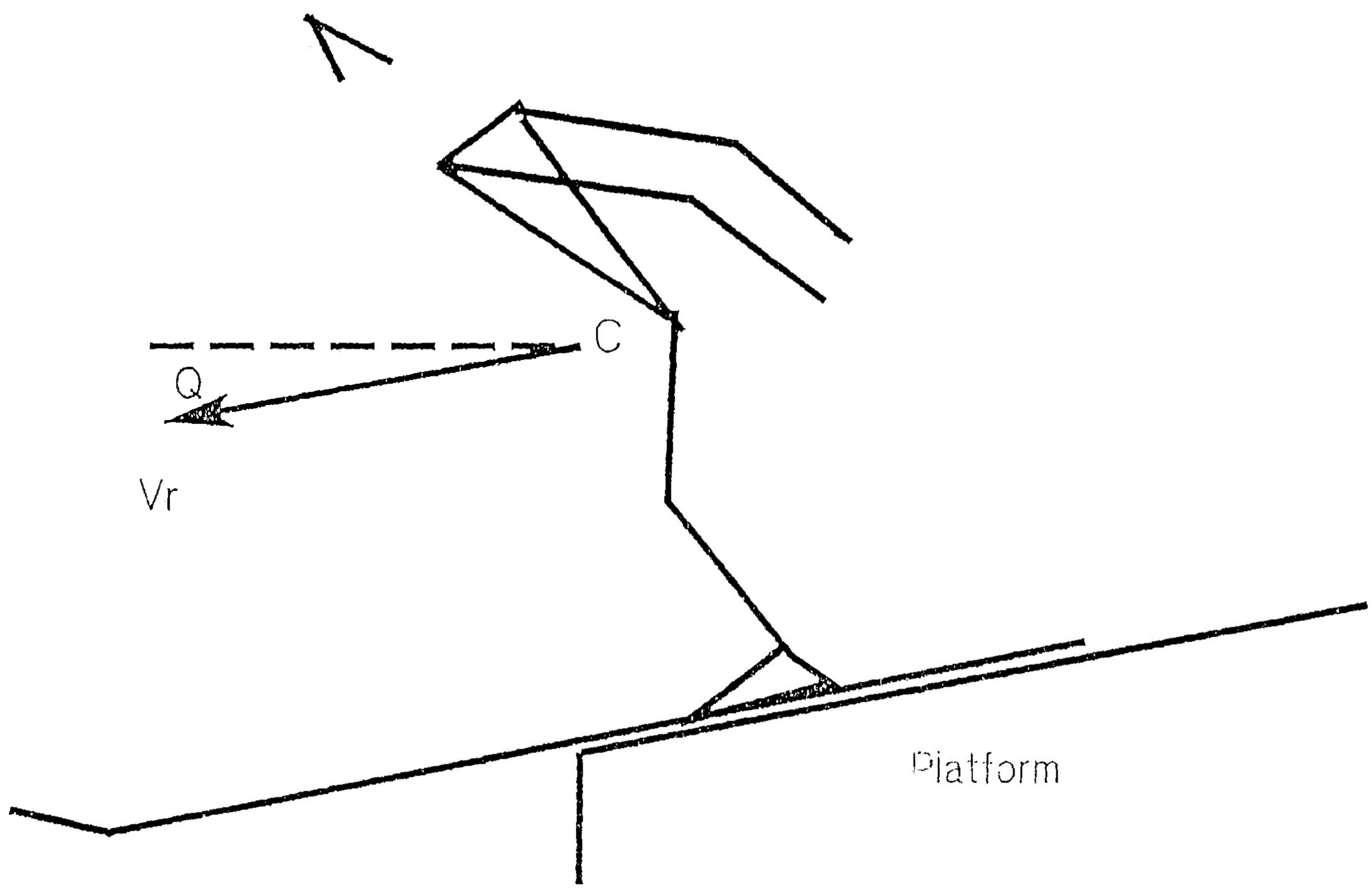
The angular displacement was determined by the degree of movement at the shoulder, elbow ,knee, trunk, leg, ski, centre of mass during the take-off phase and transition phases respectively and is reported in degrees.

Average Angular Velocities

The average angular velocity was calculated for the shoulder, elbow, knee, trunk, leg, ski, centre of mass during the take-off and transition phase respectively.

Seventy five variables were initially selected for inclusion in a correlation analysis. A complete listing of measures of all variables for each subject is presented in APPENDIX A.

Figure 7. The Take-off Angle



Q - Take-off angle which is relative to the horizontal

Data Smoothing

The data extracted from the video taped performances was smoothed using a second order Butterworth Digital Filter. The cut-off frequency of 4 Hz was selected based on the preliminary investigation.

Statistical Procedures

The statistical methods used in this study relate to:

1. Digitizing reliability
2. Descriptive statistics
3. The relationship between specific kinematic parameters and the distance jumped.
4. A multiple regression analyses

Digitizing Reliability

The reliability of the digitized video data was determined by performing two repeated measures of four segmental endpoints on four randomly selected frames for one of the trials analyzed. The analysis was performed using intra-class reliability procedures which provided a reliability estimate for the relative consistency of the researchers in digitizing the segmental endpoints (Winter, 1971. p. 283-287). The X and Y coordinates for each endpoint were treated separately.

Descriptive Statistics

Means, standard deviations, minimum and maximum values for 75 variables were generated to provide the description and provide quantification for the variables which may be associated with the distance jumped.

The Relationships between Selected Variables and the Distance Jumped

The Pearson product moment correlation technique was used to determine the existence and measure of strength of any linear relationships among the selected variables. Correlation coefficients were calculated by using subroutines from the Statistical Package for the Social Science (SPSS) package.

Multiple Correlation Analysis

Both multiple linear regression and stepwise regression analyses were used to determine the predictability of the dependent variable, the distance jumped.

The full model regression coefficients and the coefficients for stepwise regression were calculated by the computer program SPSS.

All multiple correlation analyses were computed using the SPSS program. A correlation coefficient equal to 0.374 was required for significance at the 0.05 (2-tailed) level, 0.479 for significance at the 0.01 (2-tailed) level of confidence.

RESULTS

The goal of the study was to identify, describe and quantify selected kinematic variables associated with the distance jumped by world class ski jumpers. Kinematic variables were extracted from video taped records of the top 28 jumpers in the first and second jumps of the 1994 World-cup official K-120 training rounds. The result are presented in this chapter under the following headings:

(a) Measurement reliability, (b), Quantification of variables and the relationships between selected variables and distance jumped, (c) Relationship among the selected variables, and (d) Multiple regression analyses.

Measurement Reliability

Intraclass reliability coefficients (R) were computed separately for the X and Y coordinates from 2 repeated measures of four randomly selected video trials. The correlation values presented in Table 2 indicated that the investigator was consistent in estimating the planar coordinates of endpoints used in the calculation of the centre of mass and linear displacement. Equally consistent measurements were assumed to exist for those trials and segmental endpoints not included in the analysis. The data in Table 2 revealed that the horizontal coordinates were located with greater precision for four of the endpoints than the vertical coordinates.

Table 2

Intraclass Reliability Coefficients for Location of Segmental Endpoints

Endpoint	X coordinate	Y coordinate
Left Elbow	.9969	.9962
Left Shoulder	.9915	.9895
Left Knee	.9985	.9063
Left Ankle	.9995	.9912

The Relationships Between Selected Variables and the Distance Jumped

Means, standard deviations, minimum and maximum values for 75 variables were generated to enhance the description and provide quantification for the variables which may be associated with the distance jumped. All of these results are presented in Table 6.

A correlation analysis was then conducted. All multiple correlation analyses were computed using SPSS sub-routines. A correlation coefficient equal to .374 was required for significance at the .05 level of confidence. A correlation coefficient equal to .479 was required for significance at the .01 level of confidence. First, seventy five variables were selected for inclusion in the correlation analysis to determine which variables were significantly correlated to the distance jumped. Six variables were found to meet a significance level of $P<.05$ level and were selected for further discussion and analysis. The six significant product moment correlations between selected variables and the distance jumped are presented in Table 3.

A description of the results for the six independent variables selected from the correlation analysis with the dependent variable, distance jumped and the angle of velocity, which was frequently discussed in literature are presented below:

<u>Distance jumped</u>. The mean value for the distance jumped was 119.38 m. The minimum and maximum scores were 102.5

and 134.5 m with a standard deviation (SD) of 9.37. Values for the distance jumped varies greatly in different competitions due to different conditions of the hill, starting gate, weather and so on. It is not useful to make comparisons to results from other hills or competitions.

In-run speed (Measured by official). The mean value for in-run speed was 25.69 m/s. The minimum and maximum scores were 25.10 and 27.00 m/s (SD=.37). Values for the in-run speed reported in the literature have ranged from 22 m/ s to 27 m/s (Reichert, 1980)

Horizontal position of centre of mass relative to the ankle at B1. The mean value for the horizontal position of the C/M relative to the ankle at B1 was -.14 m (here a negative value indicated that the position was in the front of the ankle). The minimum and maximum scores were -.21 m and -.07 m (S=.03).

C/M angle relative to the direction of the approach at B1. The mean value for the C/M angle (the angle between C/M, toe and the direction of the approach) at B1 was 104.8 degrees. The minimum and maximum scores were 96.9 and 112.4 degree (SD=3.34).

Average vertical velocity of the centre of mass during the transition phase. The mean value for average vertical velocity during the transition phase was -3.41 m/s. The minimum and maximum scores were -4.1 and -2.9 m/s (SD=.29).

Angular velocity of the C/M around the ankle during take-off phase. The mean value for the angular velocity of the C/M during the transition phase was -51.03 deg/s. The minimum and maximum scores were -88.0 and -5.0 deg/s (SD=18.81).

Angular displacement of the C/M during transition phase. The mean value for the angular displacement of the knee during transition phase was -8.12 degrees. The minimum and maximum scores were -13.4 and -12 degrees (SD=2.68).

Angle of take-off Velocity. The mean value for the angle of velocity at T1 was 6.21 degree. The minimum and maximum scores were 4.8 and 7.7 degrees (SD=.71). The angle of take-off has been discussed in previous research using two different definitions. The first used the angle relative to the jumping platform, while the second definition used the angle relative to the horizontal plane as in this study.

The variables which correlated significantly with distance jumped at the .05 level of significance are presented below:

1. The independent variable, horizontal position of centre of mass relative to the ankle at the beginning of take-off phase, correlated negatively with the dependent variable, distance jumped ($r=-.4696$ $P<.05$ 2-tailed). This result suggests that the further the horizontal position of the centre of mass from the ankle, the greater the distance that will be jumped.

2. The independent variable, C/M (centre of mass) angle at the beginning of take-off, also correlated negatively with the dependent variable, distance jumped ($r=-.3956$ $p<.05$ 2-tailed). This indicated that as the C/M angle at the beginning of take-off decreased the distance jumped increased.

3. The independent variable, the average vertical velocity during the transition phase, correlated positively and significantly with the dependent variable, distance jumped ($r=.3899$ $p<.05$ 2-tailed). This result indicated that as the vertical velocity increased during transition the distance jumped increased.

4. The independent variable, the average angular

velocity of the C/M angle during the take-off phase, correlated positively and significantly with the dependent variable, distance jumped ($r=.3878$ $P<.05$ 2-tailed). This indicated that the faster the knee extension the greater the distance jumped.

5. The independent variable, the angular displacement of the C/M angle during transition phase, correlated positively and significantly with the dependent variable, distance jumped ($r=.4564$ $p<.05$ 2-tailed). This result indicated that the greater the C/M angular displacement the greater the distance jumped.

6. The independent variable, the in-run speed , correlated positively and significantly with the dependent variable, distance jumped ($r=.4330$ $p<.05$ 2-tailed). This result indicated that as the in-run speed increased the distance jumped increased.

The hypothesis that there is a relationship between selected independent variables and the dependent variable, distance jumped, was therefore supported by the results.

The rest of the variables did not correlate significantly ($r<.374$ $P>.05$ 2-tailed) with the dependent variable, distance jumped.

Table 3

Correlation between selected independent variables and dependent variables, distance jumped (N=28)

Correlation:	DIS	SPEED	BCAA	BA6
DIS	1.0000	.4330*	-.4696*	-.3956*
SPEED	.4330*	1.0000	-.6054***	-.5452**
BCAA	-.4696*	-.6054***	1.0000	.4902**
BA6	-.3956*	-.5452**	.4902**	1.0000
W6	.3878*	.6046***	-.3270	-.7439***
VFV	.3899*	.2015	-.4914**	-.1868
ZF7	.4564*	.2509	-.3610	-.0967
QTT	-.3137	-.1829	.3845*	.2715

2-tailed Signif: * - .05 ** - .01 *** - .001

Dis - Distance jumped.
Speed - In-run speed.
BCAA - The horizontal position of the C/M relative to the ankle at B1.
BA6 - The C/M angle at B1.
W6 - The average angular velocity of the C/M during take-off phase.
VFV - The average vertical velocity of the C/M during the transition phase.
ZF7 - The angular displacement of the C/M during the transition phase.
QTT - The angle of the resultant velocity at the edge of the platform (take-off angle).

(continued)

Correlation between selected independent variables and dependent variables, distance jumped (N=28)

Correlation:	W6	VFV	ZF7	QTT
DIS	.3878*	.3899*	.4564*	-.3137
SPEED	.6046**	.2015	.2509	-.1829
BCAA	-.3270	-.4914**	-.3610	.3845*
BA6	-.7439***	-.1868	-.0967	.2715
W6	1.0000	.1380	.1627	-.1323
VFV	.1380	1.0000	.2210	-.8001***
ZF7	.1627	.2210	1.0000	-.3012
QTT	-.1323	-.8001***	-.3012	1.0000

2-tailed Signif: * - .05 ** - .01 *** - .001

Dis - Distance jumped.
Speed - In-run speed.
BCAA - The horizontal position of the C/M relative to the ankle at B1.
BA6 - The C/M angle at B1.
W6 - The average angular velocity of the C/M during take-off phase.
VFV - The average vertical velocity of the C/M during the transition phase.
ZF7 - The angular displacement of the C/M during the transition phase.
QTT - The angle of the resultant velocity at the edge of the platform (take-off angle).

Relationships among the Selected Independent Variables

A number of the independent variables correlated significantly at .05 or .001 with other independent variables and are discussed below:

1. The horizontal position of the C/M at B1 correlated negatively and significantly with in-run speed ($r=-.6054$ $p<.001$ 2-tailed). This suggests that the further the horizontal position of the C/M from the ankle at B1 the greater the in-run speed.

2. The horizontal position of the C/M at B1 correlated positively and significantly with C/M angle at B1 ($r=.4902$ $p<.01$ 2-tailed). This result suggests that the greater the C/M angle the closer the position of C/M to the ankle at B1.

3. The horizontal position of the C/M at B1 correlated negatively and significantly with the average vertical velocity of the C/M during the transition phase ($r=-.4914$ $p<.01$ 2-tailed). This result suggests that the smaller the average vertical velocity of C/M during the transition phase the closer the position of C/M to the ankle at B1.

4. The C/M angle at B1 correlated negatively and significantly with in-run speed ($r=-.5452$, $P<.01$ 2-

tailed). This result indicated that the greater the in-run speed the smaller the C/M angle at B1.

5. The C/M angle at B1 correlated negatively and significantly with the average angular velocity during take-off phase ($r=-.7439$, $P<.001$ 2-tailed). This result indicated that the greater the average angular velocity during take-off phase the smaller the C/M angle at B1. This can be explained by a mathematical relationship between these two variables. The average angular velocity during take-off was derived from the angle at B1 and T1 and its value was therefore dependent on the angle value at B1. This is an example of extreme multi-collinearity.

6. The average angular velocity during the take-off phase correlated positively and significantly with the in-run speed ($r=.6046$, $P<.001$ 2-tailed). This result indicated that the greater the in-run speed the greater the average angular velocity during take-off phase.

Six correlations met the .01 or .001 level of significance. The hypothesis that there are relationships among selected independent variables was, therefore, supported by these variables.

Multiple Regression Analyses

Five of the original six independent variables which correlated significantly with distance were selected for inclusion in a multiple regression analysis. Results of the correlation analysis indicated a need to delete the variable, the C/M angle at B1 in order to eliminate a case of extreme multi-collinearity.

A multiple regression model was computed to predict the jumping distance using the method of least squares. The results of this analysis are presented in Table 4. The prediction equation with variables arranged in the order of their importance in predicting distance jumped is presented below:

$$Y = 71.1527 + 3.1623 \times X1 + 7.006 \times X2 - 31.5062 \times X3 + .0971 \times X4 + 1.0639 \times X5$$

where:

Y = Dependent variable (distance jumped).

X1 = In-run speed.

X2 = Average vertical velocity during transition.

X3 = The horizontal position of the C/M relative to the ankle at B1.

X4 = Average Angular velocity of C/M during the take-off phase.

X5 = The C/M angular displacement during the transition phase.

The multiple correlation coefficient, an indication of the amount of the population that is accounted for by the model, was .6375. The F-test statistic, a measure of how good the model is , was 3.01255, the significance of F=.0321, $P<.05$. therefore the hypothesis that there is an order to the relative importance of each of the selected independent variables in predicting the jumping distance, was confirmed at the .05 level of significance.

TABLE 4

Regression Analysis to Predict Distance from Elected Variables

Variable	B	SE B	Beta	T	Sig T
SPEED	3.162374	6.204545	.126454	.510	.6153
VFV	7.006064	6.252098	.214113	1.121	.2745
BCAA	-31.506242	66.468864	-.114157	-.474	.6402
W6	.097131	.103141	.194968	.942	.3566
ZF7	1.063985	.617555	.304439	1.723	.0989
(Const.)	71.152731	156.673154		.454	.6542

The five independent variables used in the full regression analysis were also selected for inclusion in a stepwise analysis. The stepwise analysis eliminated those variables which did not contribute significantly to the regression. The results of this analysis were presented in Table 5. The stepwise equation for predicting the distance jumped was:

$$Y' = 123.84 - 75.7464 \times x1 + 1.1087 \times x2 + .1227 \times x3$$

where:

Y′= Distance jumped

X1 = The horizontal position of the C/M relative to the ankle at beginning of take-off phase.

X2 = The angular displacement during the transition phase.

X3 = The average angular velocity of the C/M during take-off phase.

The multiple correlation coefficient for the model was .60768. This result indicated that the model which included only three of the original six variables was almost as useful in predicting jumping distance.

TABLE 5

Stepwise Regression to Predict Distance from Selected Variables

Variable	B	SE B	Beta	T	Sig T
BCAA	-75.746422	50.155234	-.274453	-1.510	.1440
ZF7	1.108760	.608314	.317251	1.823	.0808
W6	.122793	.085570	.246481	1.435	.1642
(Constant)	123.849093	11.665366		10.617	.0000

DISCUSSION

The results of the data analysis will be discussed under the following headings: (a) Descriptive analysis, (b) Correlation analysis, (c) Regression analyses, (d) Similarities and differences between the traditional style of jumping and V-style.

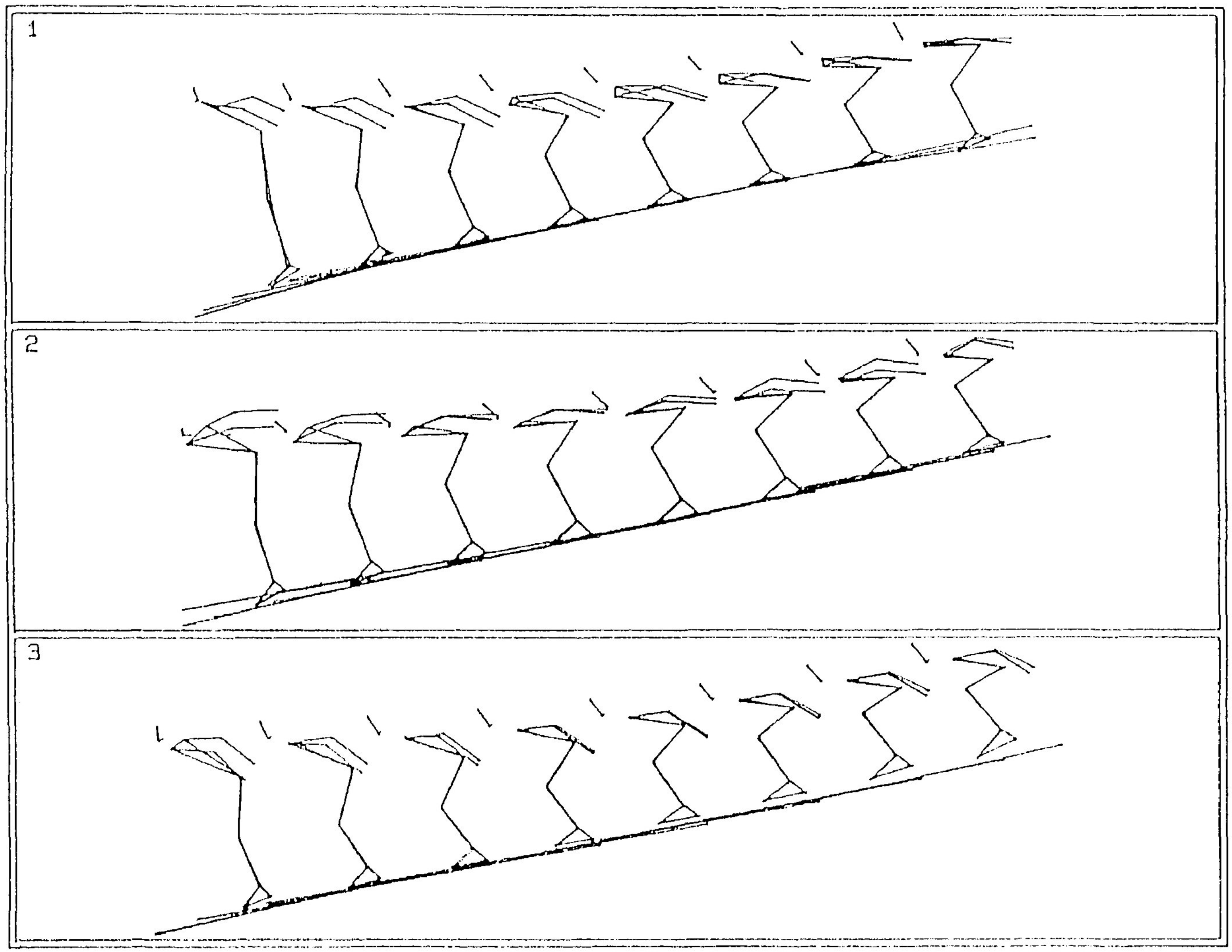
Descriptive analysis

Take-off phase

The top six jumpers (One Austrian, one Norwegian, two Japanese, one Canadian, one Finn) were selected for a descriptive analysis. Characteristics of the best jumpers were identified and are as follows:

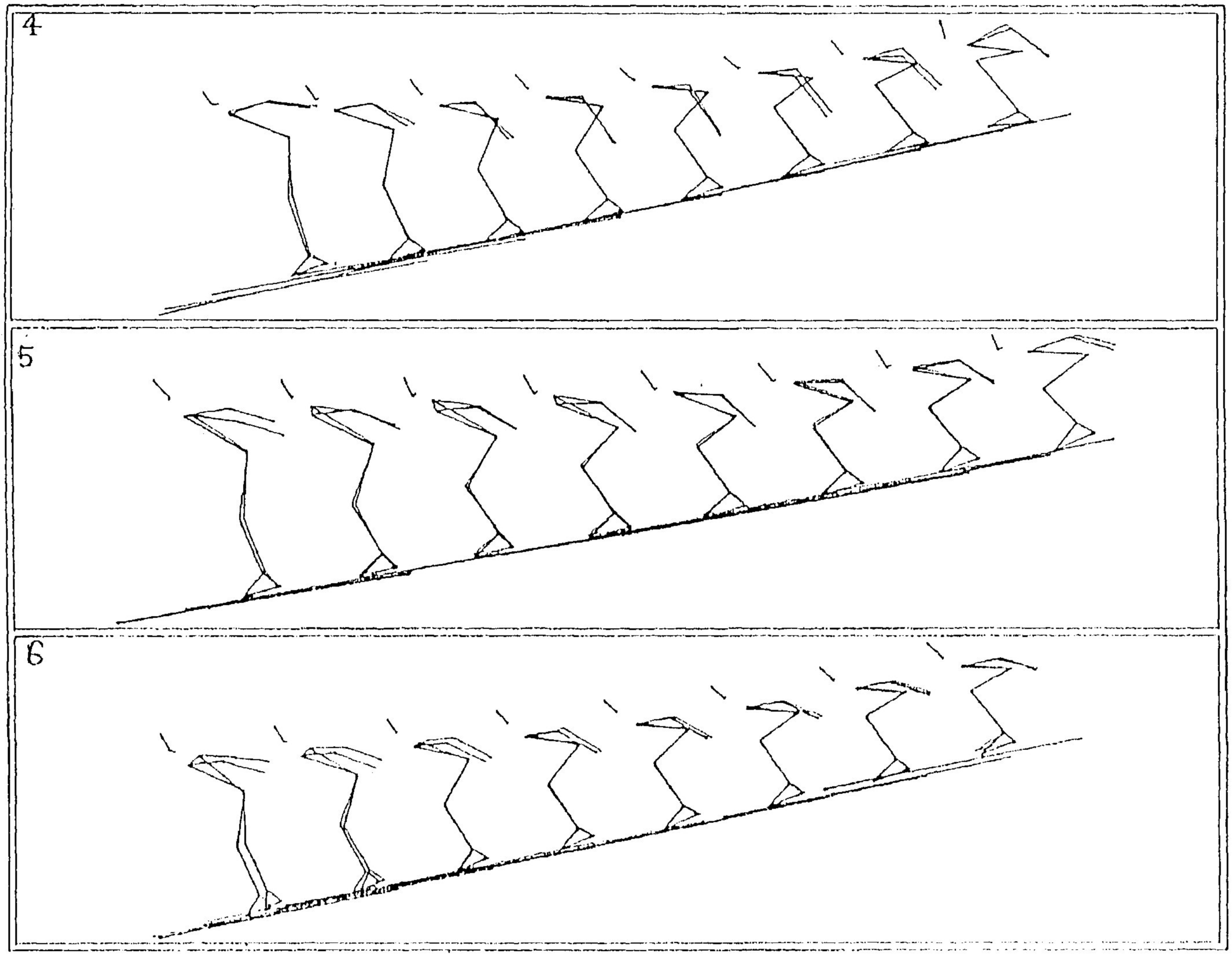
1. The horizontal position of centre of mass relative to the angle of the body of the six best jumpers appeared to be a lower position in the direction perpendicular to the track at the beginning of take-off. This can be clearly seen in Figure 8. The position of the body was such that the horizontal position of the centre of mass was always in front of the ankle, which demonstrated a forward position at the beginning of the take-off. Campbell (1990) found that the position of the centre of mass of highly skilled

Figure 8. The frames of take-off of top six jumpers



1. Austrian 2. Norwegian 3. Japanese

(continued)



4 Canadian 5. Finn 6. Japanese

jumpers was more forward relative to the ankle than for less skilled jumpers.

In Figure 8 it can be seen that the six jumpers maintained small leg, trunk and knee angles at beginning of take-off. The angle of the trunk and knee, however, varied across individuals. The top two jumpers positioned their back more flat and parallel to the skis than did the rest of jumpers. The arm position appeared to be similar for all of the top six with the exception of one jumper. Five of the jumpers' elbow angles appeared slightly different. The upper arm was almost positioned parallel to the skis. At the same time, the elbow of the Austrian jumper was almost flat and parallel to both the trunk and skis. These results partly support the descriptions of the optimal position during in-run or the beginning of take-off reported by Campbell (1990): "the back should be flat ... The arms are positioned back along the trunk, parallel to skis" (p.316).

2. It can be seen from Figure 8 that the body positions of the six jumpers also demonstrated similar angles of knee and leg but different angles at the trunk and shoulder at the edge of the platform. The

knee and leg angle appeared to be extended, which lifted the position of the centre of mass. The shoulder angle of the Norwegian, Canadian, one Japanese and one Finish jumper increased at the edge of platform and maintained a higher arm position from this instant. The shoulder angle of the Austrian and another Japanese (third best) appeared not to change and was maintained along the trunk at this instant. All jumpers had larger trunk angle than the second best. The second jumper attained a smaller trunk angle and greater shoulder angle at the edge of platform.

3. The arm action of the jumpers appeared to have different rotation characteristics in terms of direction and rate. The arms of the first top two jumpers had a rotation in counter-clock direction. The arm of the rest (Japanese, Canadian) first demonstrated a rotation in the clockwise direction and then rotated in the counter-clockwise direction. The rate of the rotation appeared to vary. The smallest rotation arrangement of the arm of two Japanese can be seen during whole take-off from Figure 8.

4. It also can be seen from the stick Figure 8 that the extension of the lower extremity and the trunk

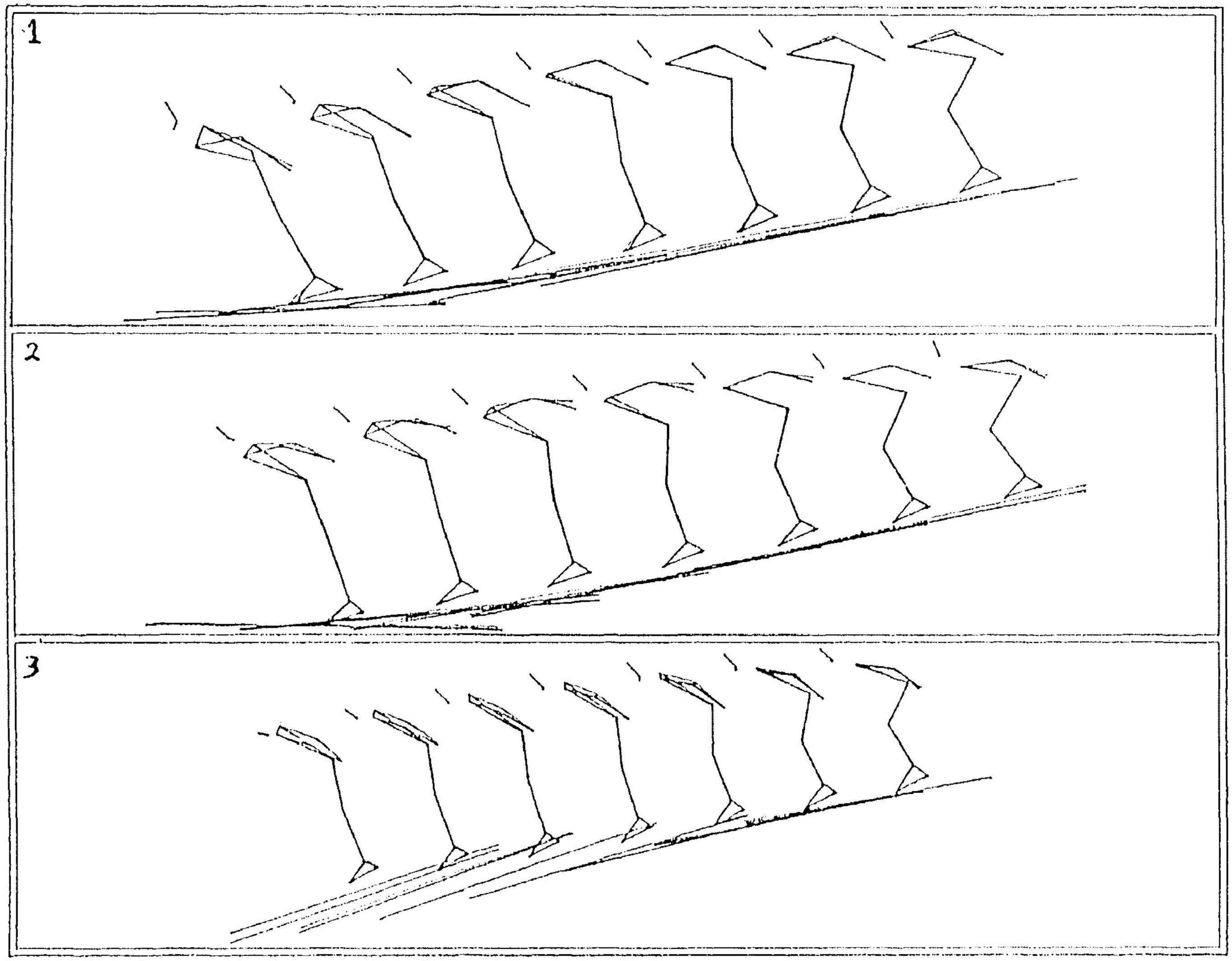
began at about five meters before the platform. The arm action of the jumpers appeared to have different sequences and timing. Three jumpers' arm actions began at about five meters before the platform with the arm positioned along the trunk. Two of the jumpers' arm actions first rotated in the clockwise direction and began at almost the same instant as that of the above jumpers, then the arm action rotated in the opposite direction at about 3 meters before platform. One of the Japanese jumpers demonstrated a particular arm style, which began with a slight rotation at the beginning of take-off and then maintained a constant shoulder angle during the take-off phase.

Beginning of the Transition into Flight

1. After the edge of platform, the centre of mass of the body of the top six jumpers showed a more forward and higher position than during take-off phase (See Figure 9).

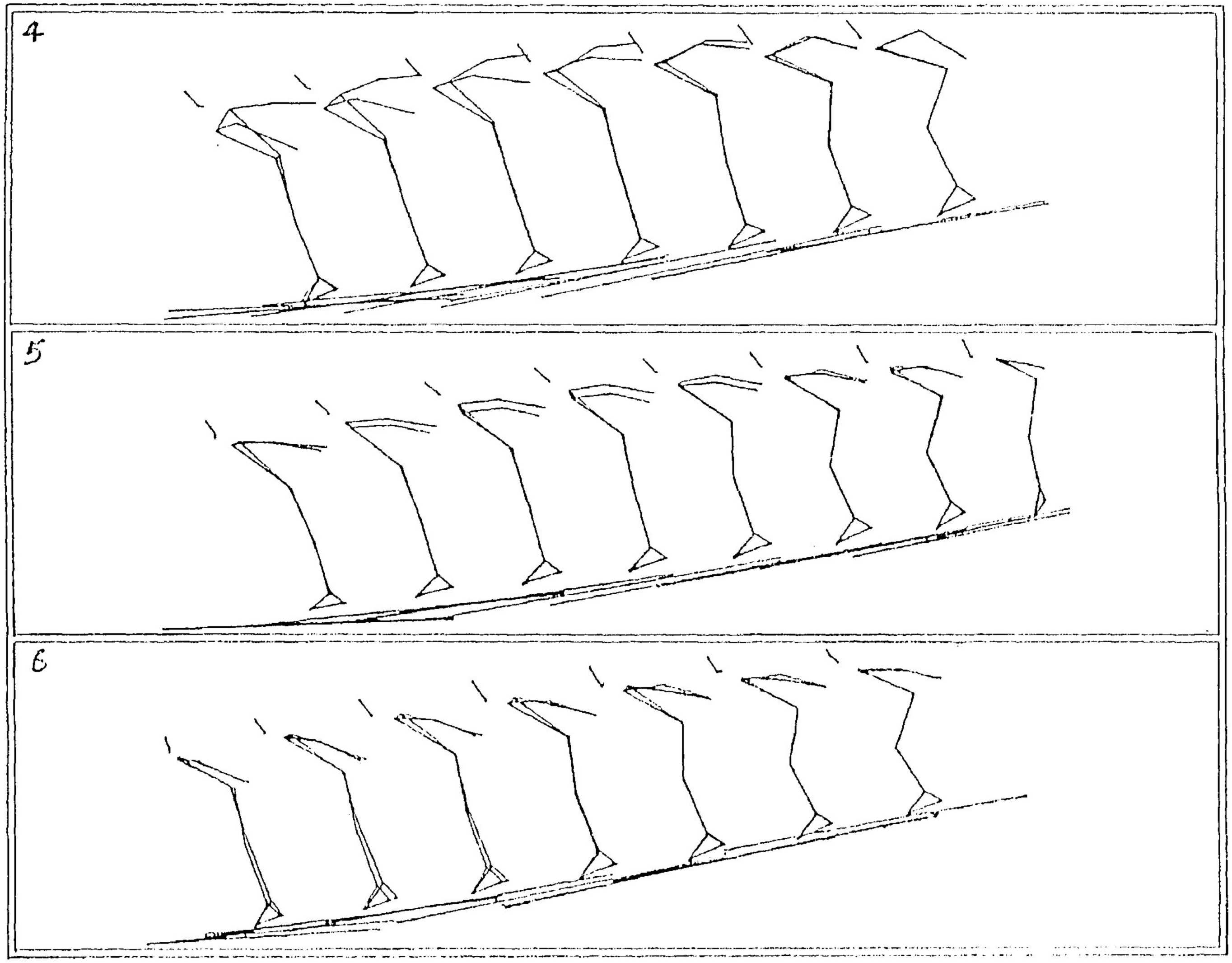
2. The arm position of the jumpers continued to exhibit differences among the six jumpers during transition. The arms of four jumpers achieved a higher position relative to the trunk. Two jumpers' arms showed a lower position relative to the trunk.

Figure 9. The frames of transition of top six jumpers



1. Austrian 2. Norwegian 3. Japanese

(continued)



4 'Canadian Finn 6. Japanese

Based on the data from the descriptive statistical analysis, additional characteristics of the best jumpers during take-off and transition phases were found:

1. The value of the horizontal distance from the maximum knee position to the edge of the platform (The mean value was 3.53 m after the edge of the platform in this study) was larger than reported in the literature. (Vaverka defined distance larger than two m after the platform as a "late take-off" and less than one m as a "early take-off"). The reason for the difference between the results of this study and previous studies might be due to the definition of the critical point E1. E1 was defined as the frame in which the maximum knee extension angle was exhibited in this study.

2. The position of C/M relative to the ankle increased its' value in both the approach and normal directions during the take-off and transition phase. This result showed that the motions of body were forward and created a good preparation position for the rotation.

3. The angle of the segments increased from B1 to

E1 (in both contact take-off phase and non-contact phase) except for the angle of C/M which decreased during the same period. This result indicates that the extension action of the segments for take-off consistently happened over both phases.

4. The angular velocity of the shoulder and knee during the take-off phase was larger than during the transition phase. The angular velocity of the elbow during the transition phase was larger than the take-off phase. (both variables mentioned above were calculated during the same period of time). This result suggests two things: firstly, the acceleration process of shoulder and knee during the take-off phase was quicker. Secondly, the movement of each segment was different for take-off and transition.

5. Velocities in the approach and resultant directions increased from B1 to T1, this indicated that the take-off phase was an acceleration process. Velocities in the horizontal and resultant direction decreased from T1 to E1, this result indicated that the transition phase was a deceleration process. The maximum value of the approach velocity and resultant velocity happened during the take-off phase. The fact

that the velocity value in take-off phase was larger than that of transition demonstrated the conclusion of previous researchers - the take-off phase was a key phase of ski jump.

6. The approach velocity at B1 was almost equal to the in-run speed recorded by the competition officials. This fact demonstrated that the set of critical point B1 was suitable as the beginning of take-off phase.

7. The ski angle showed a few change in the transition phase analyzed. This fact indicated that the movement of the body which attempted to adjust to a good aerodynamic body position for flight mainly happened by position of the body segments rather than ski during this initial transition period.

Correlation Analysis

1. There was a moderate significant relationship ($r=.433$, $P<.05$) between the in-run speed and body position at take-off. The in-run speed not only correlated with the distance jumped ($r=.433$, $P<.05$), but also with the position of C/M ($r=-.6054$, $P<.01$) and the C/M angle ($r=-.5452$, $P<.01$)) at the beginning of

take-off. This suggests that there is a moderate relationship between the action of the jumpers in different phases. This fact also supports the findings of previous researchers (Vaverka, 1992).

"The task of the in-run phase was to achieve the maximum speed of the run possible in preparation for the take-off phase (aerodynamic factor), to create an optimum body position for the subsequent take-off (factor related to the optimum body position), and to continually solve the equilibrium and stability problem of body position (factor related to equilibrium)."

2. There also was a moderate significant relationship ($r=-.4914$, $P<.01$) between the average vertical velocity during transition phase and body position at the beginning of take-off. This result also supports the findings of Vaverka (1994).

3. The weak correlation between the Take-off angle at the edge of platform and distance jumped was not precisely met at the .05 level ($r=.374$) of significance, however still weak, the coefficient ($r=-.3137$) was close to the .05 level of significance. As an important parameter, the take-off angle at the edge of the platform has been considered and discussed by

previous researchers as an important factor affecting the distance jumped.

4. The weak relationship between the selected variables and distance jumped may be explained by the complexity of the technique of the ski jump. The performances of the ski jump were influenced by multiple factors during the take-off and flight. The results of this study indicated that the stronger relationships existed among selected variables and demonstrated that some variables may be dependent on one another. Excellent jumps are dependent on the precise timing and sequence of many factors. While there were not strong correlations between the independent variables and the distance jumped, the best jumpers did demonstrates particular characteristics.

Regression Analyses

A multiple regression model was derived which predicted, at the .05 significance level, the distance jumped in ski jump.

Two regression models were derived to predict the distance in ski jump. Both models resulted in significant predictions and provided insight into several facets of the ski jump as well as an understanding of the use of statistical modelling in Biomechanics.

The multiple correlation coefficient of r=.6375 for the full regression model was high and provided a more general picture of the relative contribution of each of the structural and mechanical predictor variables.

The resulting prediction equation suggested that ski jumpers concerned with maximizing their jumping distance should (a) generate a greater in-run speed in the in-run phase, (b) create an optimal body position at the beginning of the platform, (c) create a maximum vertical velocity, (d) complete a take-off action in optimal sequence and timing, (e) complete a quicker body rotation around the ankle during the take-off phase.

The stepwise analysis, which produced a model comprised of a subset of variables to predict distance, also resulted in a high multiple correlation (r=.6076). This indicated that the model which included only three of the original six predictors was almost as useful in predicting distance as the full model.

From the stepwise regression model, some interpretations can be made regarding advantageous technique characteristics of world class ski jumpers. It appeared that the three most important factors for highly skilled ski jumpers were: the horizontal position of C/M relative to the ankle at the beginning of take-off, the angular displacement of the C/M around the ankle during the transition phase, and the average angular velocity of the centre of mass during the take-off phase.

Similarities and Difference between the Traditional Style of Jumping and the V-Style

Similar results to those reported in previous research which focused on the traditional style were found in this study, in which all jumpers used the V-style technique. The variables which related to the distance jumped in this study were: a) The in-run speed, b) The position of centre of mass relative to the ankle, c) The average vertical velocity of the centre of mass during the transition phase, d) The angular velocity of the centre of mass during the take-off phase, e) The angular displacement of the centre of mass during transition phase.

Campbell (1990) reported the variables which related with distance jumped during take-off phase of traditional style jumps:
a) the position of centre of mass relative to the base of support (ankle), b) the angle of the lower leg, c) the normal acceleration and velocity, d) the take-off angle and e) the angular velocity at the hip and knee.

In this study, all jumpers had positioned their centre of mass ahead of the ankle and were the top jumpers at the world-class level. The results of this study supported the finding of Campbell's: "The highly skilled jumpers has positioned the centre of gravity more forward than the less skilled skier (1990, p. 317)".

The result that average vertical velocity during transition phase related to distance in ski jumping demonstrated the importance of the extension of segments, which also indicated that the ability to generate force in the direction perpendicular to the track should be a key dynamics factor in the take-off phase when jumpers try to achieve greater distance.

The values for the trunk angle at take-off in this study were found to be quite close to the suggestions made by previous researchers: "immediately after take-off the trunk should be positioned at an angle of 28 degrees with air flow for the most aerodynamically efficient preflight position, ... a range from 20 to 40 degrees was acceptable" (Campbell 1990, p. 317). Campbell reported that an average angle of the trunk was 22 degrees for the top nine jumpers, 17.5 degrees for less skilled jumpers in the 1979 Pre-Olympic games. In this study, the mean value for trunk angle of 28 jumps at the edge of the platform was 24.38 degrees, the minimum and maximum value were 9.6 and 38.3 degrees (SD=7.32). This result supports the statement that the larger trunk angle exposes more surface area to the air to produce a favourable aerodynamic body position at the edge of the platform for flight.

The purpose of the take-off was to keep the velocity obtained during the in-run phase. This statement can be found in the literature. However, the author has not been able to find any discussion in the literature on whether or not there is an acceleration or deceleration of the centre of mass during the take-off. In this study, either the approach velocity or normal velocity and resultant velocity at the edge of the platform appeared to increase compared to that at the beginning of take-off. This result indicated that the movement of the centre of mass throughout the take-off phase was accelerating. This may be explained by the fact that the gravity consistently acted on the body to generate an acceleration due to the slope of platform, and the friction change value which was created by the segment extensions was always smaller than the approach component of gravity. Details on the forces acting on the jumper can't be discussed from the results of this study, as no forces were calculated.

The mean values for the horizontal distance from the moment of the maximum knee angle to the edge of platform was -3.53 m (after the edge). The minimum and maximum scores were -4.7 and -2.20 m (SD=.78) in this study. Vaverka (1994) reported that the optimal range from the moment of take-off completion to the edge of platform was .21 m before and .15 m after the edge with the optimal range of the knee angle in the moment of the take-off completion: Ak = 135 to 141 degree. The difference between this study and the findings of Vaverka (1994) might originate from slight differences in the definitions used in both studies. This result demonstrated the importance of determining the accuracy of take-off.

SUMMARY, FINDINGS, CONCLUSIONS, RECOMMENDATIONS

Summary

The purpose of the study was to identify, describe, and quantify selected kinematic variables associated with the successful performance of the ski jump. Secondly, this study attempted to determine the statistical contribution of specific kinematic variables at take-off and the beginning of the transition phase for the distance jumped.

Experimental Procedures

The subjects for this investigation were 60 highly skilled competitors participating in the 1994 World Cup K-120 event. Twenty eight jumps were selected from the top 40 performances in the first and second jumps of the official training day for the K-120 event. Data was previously collected for 27 National and Junior jumpers during a preliminary investigation on July, 1992, at Big Thunder National Training Centre First Annual Plastic Jump competition.

Data were collected by using two Panasonic video cameras (Type SVHS) equipped with a high speed shutter. The subsequent analysis procedure split each picture into two fields providing a sampling rate of 60 FPS.

The cameras were levelled and positioned at a 90 degree angle to the plane of motion. All jumpers were filmed as they passed through the targeted zones. The first camera was located at 10 m from the take-off platform which allowed a field width of approximately seven meters for the take-off phase. The second camera was located at twenty five meters from the platform to record a side view of the beginning of the transition from take-off into flight phase. The field width of this view was seven meters.

Data for the distance jumped were collected from the records for the two official training jumps held the first day of official competition.

The 2D Peak Performance Video Analysis System was used to extract the horizontal and vertical coordinates for a 23 segment model. The centre of mass was calculated by a model which included 14 body segments. The data were smoothed using a second order Butterworth digital filter and processed to compute linear displacements and velocities and angular displacements and angular velocity values. A computer program written by the author was used to process the data calculated for the variables selected in this study. Statistical treatment of selected kinematic variables was performed using the appropriate computer programs from SPSS.

Findings

The findings of this investigation are summarized under the following headings: (a) Relationship between selected variables and distance jumped, (b) Multiple regression analysis, (c) Descriptive Analyses.

Relationship between selected Variables and distance Jumped

The following independent variables significantly correlated with distance jumped.

1. In-run speed (moderate).

2. Average Vertical velocity of the centre of mass during the transition phase (weak).

3. Horizontal position of centre of mass relative to ankle at the beginning of take-off phase (weak).

4. Average angular velocity of the centre of mass around the ankle during take-off phase (weak).

5. Angular displacement of the centre of mass during transition phase (moderate).

6. The angle of the centre of mass relative to the direction of approach at the beginning of the take-off phase (weak).

Multiple Regression Analysis

1. The full multiple regression equation for predicting the distance with the variables arranged in the order of their importance was:

$$Y = 71.1527 + 3.1623 \times X1 + 7.006 \times X2 - 31.5062 \times X3 + .0971 \times X4 + 1.0639 \times X5$$

where:

Y = dependent variable (distance jumped).

X1 = In-run speed.

X2 = Average vertical velocity during transition.

X3 = The horizontal position of the C/M relative to the ankle at B1.

X4 = Average Angular velocity of C/M during the take-off phase.

X5 = The C/M angular displacement during transition phase.

2. A stepwise regression model for predicting the distance jumped was derived. The equation for

predicting the distance, with variables arranged in the order of their important to the prediction, was:

$$Y' = 123.84 - 75.7464 \times x1 + 1.1087 \times x2 + .1227 \times x3$$

where:

Y'= distance jumped

X1 = The horizontal position of the C/M relative to the ankle at beginning of take-off phase.

X2 = The angular displacement during the transition phase.

X3 = The average angular velocity of the C/M during take-off phase.

Descriptive Analyses

The following results were noted:

1. There was a relationship between in-run speed and body position at the take-off.

2. The wind speed was a factor which will affect the distance jumped.

3. The value of the horizontal distance from the maximum knee extension to the edge of platform was larger than reported in the literature.

4. The position of the C/M relative to the ankle

increased its' value in both the approach and normal direction during the take-off and transition phases.

5. The angle of the segments increased from B1 to E1 except for the angle of the C/M which decreased during the same period.

6. The angular velocity of the shoulder and knee during the take-off phase was larger than during the transition phase.

7. The acceleration of the centre of the body was found during the take-off phase. The negative deceleration of the centre of mass was found during the transition phase.

8. The definition of the critical point B1 was deemed suitable for the beginning of the take-off phase.

9. The movement of the body which aimed to create a good aerodynamic body position for flight was mainly dependent on the body segments rather than the ski.

Conclusions

1. It is possible to identify, describe, and quantify from video analysis, the important kinematic

variables related to world-class jumper's performance of the ski jump.

2. Multiple regression statistical modelling can be a valuable technique to help in analyzing the mechanics of the ski jump.

3. The results of the regression analysis suggest that jumpers who want to increase the distance should generate as large as possible in-run speed, create an optimum aerodynamic body position with forward lean movement, take a quicker drive segment extension to begin a forward lean rotation, at the same time keep and increase continually the velocity in the take-off phase, keep and increase the forward lean movement of body and knee extension in order to create an optimum aerodynamic body position during transition phase. Jumpers should properly adjust their body position with changes in wind speed in order to obtain the benefit to the distance jumped.

4. The technique characteristics during the take-off phase of highly skilled jumpers using V-style were similar to the movements which have been identified for the traditional jump style.

5. The performances of the ski jump were

influenced by multiple factors during the take-off and flight. Excellent jumps are dependent on the precise timing and sequence of many factors.

Recommendations

The following recommendation are offered for future research:

1. The movement of body relative to platform should be considered in video analyses.

2. There is a need to employ force measurement techniques for the analysis of the take-off phase.

3. An electromyographic (EMG) analysis is recommended in order to determine the relationship among segmental actions, and the sequence of segmental movement during the take-off and transition phases.

4. Wind tunnel laboratory research is recommended in order to investigate the characteristics of skis during performance of V-Style jump.

References

Baumann, W. (1978). The biomechanics study of ski jumping. Scientific Study in Skiing in Japan, Tokyo. 1, 70-95.

Campbell, K. R. (1979). A kinematic analysis of the take-off phase in ski jumping. Unpublished master's thesis, University of Illinois, Urbana, IL.

Campbell, K. R. (1990). Biomechanics of ski jumping. In M. J. Casey (Ed.) Winter Sports, (315-323), Philadelphia: F. A. David.

Gisler, E. A. (1974). Biomechanics research in ski jumping. In F. Fetz (Ed.), Biomechanik des Skilaufs, (98-107). Austria: Inn-Verlag Innsbruck.

Grison, E. A. (1971). Ski-jumping. Moscow: Phyzcultura in sport.

Hubhard, M. (1990). A multisegment dynamic model of ski jumping. Ski Jumping Canada, 2(3), 59-67.

Hochmuth, G. (1958). Investigation of the effect of take-off on jump length in ski jumping. Wissenschafiliche Zeitschrift der DHFK, Leipzig. 1, 29-59.

Komi, P. V., Nelson. P. & Pulli. M (1974). Biomechanics of ski-jumping. Finland: University of Jyvaskyla.

Komi, P. V. (1974). Force measurements during cross-country skiing. International Journal of Sport Biomechanics, 2, 370-381.

Mcpherson, M. (1984). Factors affecting mechanical efficiency in the waltz jump. Ubpublished master's thesis, Newbrunswick University.

Nigg, B. M.(1977). Biomechanics research in ski jumping. In F. Fetz (Ed.), Biomechanik des skilaufs, (80-89). Austria: Inn-Verlag Innsbruck.

Pulli, M. (1989). Biomechanics of ski jumping. Ski Jumping Canada, 2(3), 1- 46.

Reichert, F. (1980). Maenlasku (hyppytekniikan kuvaus japerusteet). Hiihtourheilu: Valmennuskirjat oy Helsinki.

Remizov, L. P. (1984). Biomechanics of optimal flight in ski jumping. Journal of Biomechanics, 17(3), 167-171.

Ruegg, P. & Troxler.G (1979). Force measuring in ski-jumping. Master thesis in Biomechanics. Zurich, Swiss Federal Institute of Technology.

Sagesser, A., Neakomm. P. A., Nigg, B. M. & Tvoxlex, G. (1981). Force measuring system for the take-off in ski jumping. Biomechanics, 7, 478.

Strauman, F. (1927). Ski jumping and it's mechanics. Ski Schweizer, 1, 34-64.

Strauman, F. (1957). Jumping Style and it's evaluation. Sport, 1, 7-63.

Tani, I. & Iuchi, M. (1971). Flight mechanical investigation of ski jumping. In K. Kinoshita(Ed.). Scientific study of skiing in Japan, (35-52) Tokyo: Hitachi.

Tveit, P. & Pedersen, P. O. (1981). Forces in the take-off in ski jumping. Ski Jumping Canada, 2(3), 51-53.

Vimavirta, M. and Komi, P. V.(1989). The takeoff forces in ski jumping. Ski Jumping Canada, 2(3), 46-50.

Vaverka, F. (1991). Biomechanics examination of ski-jumping. Unpublished research report.

Vaverka, F. el al. (1990). The system of control and checking of the ski-jumper's training. Unpublished research report.

Vaverka, F. (1992). Kinetic analyses of the take-off. Inter sport turn 1991/1992, Innsbruck, 3(4): 1.

Vaverka, F. (1994). A diagnostic of the ski jumper's take-off accuracy based on dynamometry and kinematic analysis (in press).

Watanabe, K. (1985). Aerodynamic investigation of the flight phase in ski jumping. In Matsui. H. & Kobayashi (Eds.). Biomechanics, (856-860). Champaign, IL: Human Kinetics.

Watanabe, K. (1989). Biomechanics of sports. Ski-jumping, 4, 240-246.

Watanabe, K. (1990). Aerodynamic investigation of arm position during the flight phase in ski jumping. International journal of sport biomechanics, 5,856-860.

Winter, B. J. (1971). Statistics principles in experimental design (2nd Ed.). New York: McGraw -Hill.

APPENDICES:

A - MEAN PERFORMANCE MEASURE ON ALL VARIABLES

B - Computer Program

Appendix A

Mean Performance Measure on All Variables (N=28)

Variable	Mean	Std Dev	Minimum	Maximum
BCAA	-.14	.03	-.21	-.07
BCAI	.51	.06	.42	.66
BCAR	.00	.00	.00	.00
BCAA	-.28	.05	-.40	-.21
LCAI	.88	.07	.75	1.04
VAB	25.92	.61	24.27	26.91
VIB	-.43	.75	-1.46	1.24
VRB	25.94	.61	24.29	26.95
VAT	26.00	.81	24.42	27.34
VIT	-3.22	.59	-4.47	-2.08
VRT	26.21	.78	24.64	27.44
CA	26.25	.41	25.12	26.87
CI	-1.83	.36	-2.56	-1.16
CR	26.34	.41	25.16	26.97
BA1	17.68	11.19	-4.1	42.2
BA2	149.89	12.32	117.2	170.8
BA3	13.60	5.10	5.7	24.9
BA4	84.97	18.76	9.3	123.6
BA5	94.18	4.17	87.7	105.9
BA6	104.80	3.34	96.9	112.4
TA1	35.08	9.69	13.4	48.9
TA2	151.22	10.40	127.9	168.7
TA3	24.38	7.32	9.6	38.3
TA4	142.76	26.35	14.4	160.6
TA5	19.70	1.44	16.5	23.4
TA6	92.75	3.13	86.3	99.7
TA7	87.78	2.50	82.7	91.3
W1	61.93	62.20	-65.2	202.8
W2	10.36	67.15	-156.6	142.3
W3	67.61	33.47	-8.6	136.1
W4	290.51	61.99	154.3	431.9
W5	18.58	29.68	-88.0	72.3
W6	-51.03	18.81	-88.0	-5.0
Z1	13.30	13.34	-15.0	42.6
Z2	2.03	14.54	-32.9	30.5
Z3	14.68	7.39	-2.0	28.6
Z4	62.78	12.56	33.2	90.7
Z5	4.05	6.28	-18.5	15.2
Z6	-11.35	3.35	-18.5	-4.5

(continued)

Variable	Mean	Std Dev	Minimum	Maximum
QTT	6.21	.71	4.8	7.7
VHT	25.65	.46	23.83	26.11
VVT	-2.82	.33	-3.52	-2.16
VRRT	25.80	.46	23.93	26.27
VHE	25.37	.31	24.77	25.88
VVE	-4.18	.55	-5.30	-3.25
VRRE	25.72	.30	25.13	26.27
VFH	25.45	.36	24.10	25.90
VFV	-3.41	.29	-4.10	-2.90
VFR	25.70	.37	24.30	26.20
EA1	33.07	11.66	7.8	48.5
EA2	154.25	10.96	134.2	172.3
EA3	31.84	8.50	3.9	46.8
EA4	176.28	4.50	170.2	187.2
EA5	19.10	5.63	9.6	32.7
EA6	98.96	4.08	89.8	105.3
EA7	84.14	3.15	75.9	89.3
WF1	-10.55	36.73	-102.2	61.5
WF2	16.46	63.45	-163.5	124.9
WF3	44.41	28.05	-40.5	87.0
WF4	148.28	41.74	63.5	237.5
WF5	-3.21	27.97	-51.0	71.6
WF6	30.69	14.60	3.0	54.7
WF7	-41.58	12.62	-66.6	-6.7
ZF1	-2.01	7.11	-18.4	12.3
ZF2	3.03	12.35	-32.70	22.50
ZF3	8.67	5.48	-8.10	17.40
ZF4	28.84	7.85	12.70	47.50
ZF5	-.35	5.25	-10.20	12.90
ZF6	6.17	2.67	1.30	11.50
ZF7	-8.12	2.68	-13.40	-.12
TKLF	.08	.04	.00	.10
DKAF	-3.53	.78	-4.70	-2.20
DKIF	3.60	.22	3.20	4.00
DIS	119.38	9.37	102.5	134.5
WIND	3.08	2.22	.00	7.00
SPEED	25.69	.37	25.1	27.0

1. BCAA - It is the horizontal position of C/M relative to the ankle at the beginning of take-off (critical point B1).
2. BCAI - It is the vertical position of C/M relative to the ankle at the beginning of take-off (critical point B1).
3. LCAA - It is the horizontal position of C/M relative to the ankle at the edge of platform (critical point T1).
4. LCAI - It is the vertical position of C/M related to the ankle at the edge of platform (critical point T1).
5. VAB - It is the approach velocity of the C/M at B1.
6. VIB - It is the normal velocity of the C/M at B1.
7. VRB - It is the resultant velocity of the C/M at B1.
8. VAT - It is the approach velocity of the C/M at T1.
9. VIT - It is the normal velocity of the C/M at T1.
10. VRT - It is the resultant velocity of the C/M at T1.
11. CA - It is average approach velocity of the C/M during the take-off phase.
12. CI - It is average normal velocity of the C/M during the take-off phase.
13. CR - It is average resultant velocity of the C/M during the take-off phase.
14. Ba1 - It is the left shoulder angle at B1.
15. BA2 - It is the left elbow angle at B1.
16. BA3 - It is the angle between trunk and the approach at B1.
17. BA4 - It is the knee angle at B1.
18. BA5 - It is the angle between left leg and approach at B1.
19. BA6 - It is the angle between the line connected the C/M to toe and the direction of approach at B1.
20. TA1 - It is left shoulder angle at T1.
21. TA2 - It is left elbow angle at T1.
22. TA3 - It is angle between trunk and tangent direction of flight curve at T1.
23. TA4 - It is knee angle at T1.
24. TA5 - It is angle between ski and flight curve at T1.
25. Ta6 - It is the angle between left leg and the

tangent direction of flight curve at T1.

26. TA7 - It is angle between the line connected the C/M to toe and the tangent direction of flight curve at T1.
27. W1 - Average angular velocity of shoulder during take-off phase.
28. W2 - Average angular velocity of elbow during take-off phase.
29. W3 - Average angular velocity of trunk during take-off phase.
30. W4 - Average angular velocity of knee during take-off phase.
31. W5 - Average angular velocity of leg during take-off phase.
32. W6 - Average angular velocity of the C/M during take-off phase.
33. Z1 - Angular displacement of shoulder during take-off phase.
34. Z2 - Angular displacement of elbow during take-off phase.
35. Z3 - Angular displacement of trunk during take-off phase.
36. Z4 - Angular displacement of knee during take-off phase.
37. Z5 - Angular displacement of leg during take-off phase.
38. Z6 - Angular displacement of C/M during take-off phase.
39. QTT - It is the angle of velocity at T1.
40. VHT - It is the horizontal velocity at T1.
41. VVT - It is the vertical velocity at T1.
42. VRT - It is the resultant velocity at T.
43. VHE - It is the horizontal velocity at E1.
44. VVE - It is the vertical velocity at E1.
45. Vrre - It is the resultant velocity at E1.
46. VFH - It is average horizontal velocity during transition phase.
47. VFV - It is average vertical velocity during transition.
48. VFR - It is average resultant velocity during transition.
49. EA1 - It is shoulder angle at E1.
50. EA2 - It is elbow angle at E1.
51. EA3 - It is trunk angle at E1.
52. EA4 - It is knee angle at E1.
53. EA5 - It is ski angle at E1.

54. EA6 - It is leg angle at E1.
55. EA7 - It is C/M angle at E1.
56. WF1 - It is shoulder angular velocity during transition.
57. WF2 - It is elbow angular velocity during transition.
58. WF3 - It is trunk angular velocity during transition.
59. WF4 - It is knee angular velocity during transition.
60. WF5 - It is ski angular velocity during transition.
61. WF6 - It is leg angular velocity during transition.
62. WF7 - It is C/M angular velocity during transition.
63. ZF1 - It is shoulder angular displacement during transition.
64. ZF2 - It is elbow angular displacement during transition.
65. ZF3 - It is trunk angular displacement during transition.
66. ZF4 - It is knee angular displacement during transition.
67. ZF5 - It is ski angular displacement during transition.
68. ZF6 - It is leg angular displacement during transition.
69. ZF7 - It is C/M angular displacement during transition.
70. TKLF - It is the time from T1 to E1.
71. DkAF - It is the horizontal distance from T1 to E1.
72. DKIF - It is the vertical distance from E1 to T1.
73. DIS - It is the distance jumped.
74. Wind - It is wind speed record by competition.
75. Speed - It is in-run speed recorded by competition.

Appendix B

Computer Program

```
10  CLS
20  PRINT " The program of kinematic analysis of ski jumping"
30  CLEAR
40 DIM V(1200), P(400), K(400), H(400)
50 DIM A1(20), A2(20), A3(20), A4(20), A5(20), A6(20),A7(20)
60  PRINT
70 INPUT "the name of file to input"; NOME$
80 INPUT " how many frams in the file--", N
90 EX$="c:"
100 EEX$=".vda"
110 INPUT "number of the point--", MM
120 INPUT "number of the first fram--", BEG
130 EEX$=".cda"
140  MOME$=EX$+NOME$+EEX$
150 GOSUB 600
160 EEX$=".dis"
170 MOME$=EX$+NOME$+EEX$
180 GOSUB 690
190 GOSUB 830
200 GOSUB 1390
210 EEX$=".vda"
220  MOME$=EX$+NOME$+EEX$
230 GOSUB 600
240 EEX$=".vel"
250 MOME$=EX$+NOME$+EEX$
260 GOSUB 690
270 GOSUB 830
280 GOSUB 910
290 GOSUB 1030
300 GOSUB 1450
310 EEX$=".cda"
320  MOME$=EX$+NOME$+EEX$
330 GOSUB 600
340 EEX$=".dis"
350 MOME$=EX$+NOME$+EEX$
360 GOSUB 690
370 GOSUB 830
380 GOSUB 1390
390 EEX$=".ada"
400 MOME$=EX$+NOME$+EEX$
410 GOSUB 1970
420 GOSUB 2390
430 GOSUB 2050
440 GOSUB 2480
450 EEX$=".vel"
460 MOME$=EX$+NOME$+EEX$ :PRINT MOME$
470 GOSUB 830
480 GOSUB 910
490 GOSUB 2970
500 GOSUB 3070
```

```
510 EEX$=".dis"
520 MOME$=EX$+NOME$+EEX$
530 GOSUB 830
540 '' GOSUB 1030
550 GOSUB 2970
560 GOSUB 3100
570 GOSUB 2620
580 GOTO 30
590 END
600 '-------------- sub 1 ---------
610 OPEN "i" ,#1,MOME$
620 K=0
630 S=3*M*N+N-1
640 FOR K=1 TO S
650 INPUT #1,V(K)
660 NEXT
670 CLOSE
680 RETURN
690 '----------------- sub 2---------------
700 OPEN "o", #1, MOME$
710 P=0: J=0:L=0:I=0: P=0:K=0
720 P=P+1 :IF P>26 GOTO 800
730 J=3*P-2: L=3*P-1: I=3*P
740 FOR K = 1 TO S
750 PRINT #1, P,K,V(J),V(L),V(I)
760 J=J+M*3+1  :IF J>S GOTO 720
770 L=L+M*3+1
780 I=I+M*3+1
790 NEXT K
800 PRINT
810 CLOSE
820 RETURN
830 '---------------- sub 3 -----------
840 OPEN "i", #1, MOME$
850 FOR I=1 TO N*M
860 INPUT #1, P(I),K(I), H(I), V1(I), R(I)
870 '''PRINT P(I),K(I), H(I), V1(I), R(I)
880 NEXT I
890 CLOSE
900 RETURN
910 '''---------------- sub 4 -------------------------
920 AS =ASS*3.14159/180 :LASTT=(MM-1)*N+LAST
930 FOR G=1 TO N*M
940 IF H(G)=0 THEN H(G)=.000001
950 X(G)= ABS(V1(G)/H(G))
960 Q(G) = ATN(X(G))
970 QT(G)= Q(G)-AS
980 VA(G)= R(G)*COS(QT(G))*100: VA(G)=FIX(VA(G))/100
990 VI(G)= R(G)*SIN(QT(G))*100: VI(G)=FIX(VI(G))/100
1000 R(G)= R(G)*100: R(G)=FIX(R(G))/100
1010 NEXT G
```

```
1010 NEXT G
1020 RETURN
1030 ''-------------- sub 5--------------------
1040 AMAX =-10: IMAX=-20 :RMAX=-20
1050 AMIN =50 :IMIN=20 :RMIN=50
1060 BEGG=(MM-1)*N+BEG:LASTT=(MM-1)*N+LAST
1070 FOR G=BEGG TO LASTT
1080 QTT=Q(LASTT)*180/3.14159*10 : QTT=FIX(QTT)/10
1090 AAB=VA(BEGG):IIB=VI(BEGG) :RRB=R(BEGG)
1100  AAT=VA(LASTT):IIT=VI(LASTT):RRT=R(LASTT)
1110 IF VA(G) > AMAX THEN AMAX=VA(G)
1120 IF VI(G) > IMAX THEN IMAX=VI(G)
1130 IF R(G)  > RMAX THEN RMAX=R(G)
1140    IF VA(G)  < AMIN THEN AMIN=VA(G)
1150    IF VI(G) < IMIN THEN IMIN=VI(G)
1160    IF R(G)  < RMIN THEN RMIN=R(G)
1170 IF VA(G) = AMAX THEN MA=K(G)
1180 IF VI(G) = IMAX THEN MI=K(G)
1190 IF R(G) = RMAX THEN MR=K(G)
1200 IF VA(G) = AMIN THEN MIA=K(G)
1210 IF VI(G) = IMIN THEN MII=K(G)
1220 IF R(G) = RMIN THEN MIR=K(G)
1230 XX=XX+VA(G)
1240 YY=YY+VI(G)
1250 ZZ=ZZ+R(G)
1260 NEXT
1270 NN= LAST-BEG+1
1280 TT= (NN-1)*T*100: TT=FIX(TT)/100
1290 CA=XX/NN*100: CA=FIX(CA)/100
1300 CI=YY/NN*100: CI=FIX(CI)/100
1310 CR=ZZ/NN*100: CR=FIX(CR)/100
1320 NR=LAST-MR
1330 NRI=LAST-MIR
1340  'time between max and T1
1350 NRT=NR*T*100: NRT=FIX(NRT)/100
1360 'time between min and T1
1370 NRIT=NRI*T*100: NRIT=FIX(NRIT)/100
1380 RETURN
1390  ''------------------ sub 8 -----------------------
1400 MA=12: MT=25 : MC=26
1410 FA= (MA-1)*N+BEG: FC=(MC-1)*N+BEG
1420 TB= (MT-1)*N+BEG :TMIN=1
1430 LA= (MA-1)*N+LAST : LC=(MC-1)*N+LAST
1440 FOR J=1 TO N
1450 CMA=(MA-1)*N+J  :CMC=(MC-1)*N+J
1460 FOR K=1 TO M*N
1470 BMIN=H(TB) :CMIN=H(CMA)
1480 DIFF=CMIN-BMIN :DIFF=ABS(DIFF)
1490 NEXT K
1500 MIN(J)=DIFF
1510 NEXT J
```

```
1510 NEXT J
1520 FOR J=1 TO N
1530 PRINT J,MIN(J)
1540 IF MIN(J)<TMIN THEN TMIN=MIN(J)
1550 IF MIN(J)=TMIN THEN LAST=J
1560 NEXT J
1570 LA=(MA-1)*N+LAST :LC=(MC-1)*N+LAST
1580 MMM=(MC-1)*N+VRM  :MNN=(MC-1)*N+VRN
1590 FOR K=1 TO M*N
1600 D1(K)=H(K)*100 : D1(K)=FIX(D1(K))/100
1610 D2(K)=V1(K)*100 :D2(K)=FIX(D2(K))/100
1620 D3(K)=R(K)*100 : D3(K)=FIX(D3(K))/100
1630 BAA=D1(FA)
1640 BCA=D1(FC)
1650 BAI=D2(FA)
1660 BCI=D2(FC)
1670 BAR=D3(FA)
1680 BCR=D3(FC)
1690 LAA=D1(LA)
1700 LCA=D1(LC)
1710 LAI=D2(LA)
1720 LCI=D2(LC)
1730 LAR=D3(LA)
1740 LCR=D3(LC)
1750 TBA=D1(TB)
1760 TBI=D2(TB)
1770 DMAXR=D3(MMM)
1780 DMAXA=D1(MMM)
1790 DMAXI=D2(MMM)
1800 DMINR=D3(MNN)
1810 DMINA=D1(MNN)
1820 DMINI=D2(MNN)
1830 NEXT
1840 BCAA=(BCA-BAA)*100:BCAA=FIX(BCAA)/100
1850 BCAI=(BCI-BAI)*100 :BCAI=FIX(BCAI)/100
1860 BCAR=(BCR-BAR)*100: BCAR=FIX(BCAR)/1000
1870 LCAA=(LCA-LAA)*100: LCAA=FIX(LCAA)/100
1880 LCAI=(LCI-LAI)*100: LCAI=FIX(LCAI)/100
1890 LCAR=(LCR-LAR)*100: LCAR=FIX(LCAR)/100
1900 LCDMR=(LCR-DMAXR)*100: LCDMR=FIX(LCDMR)/100
1910 LCDMA=(LCA-DMAXA)*100: LCDMA=FIX(LCDMA)/100
1920 LCDMI=(LCI-DMAXI)*100: LCDMI=FIX(LCDMI)/100
1930 LCDNR=(LCR-DMINR)*100: LCDNR=FIX(LCDNR)/100
1940 LCDNA=(LCA-DMINA)*100: LCDNA=FIX(LCDNA)/100
1950 LCDNI=(LCI-DMINI)*100: LCDNI=FIX(LCDNI)/100
1960  RETURN
1970 ''---------------  sub 9 ----------------
1980 OPEN"i",#1,MOME$
1990 FOR K=1 TO N
2000 INPUT #1,A1(K),A2(K),A3(K),A4(K),A5(K),A6(K),A7(K)
2010 ''PRINT A1(K);A2(K);A3(K);A4(K);A5(K);A6(K)
```

```
2010 ''PRINT A1(K);A2(K);A3(K);A4(K);A5(K);A6(K)
2020 NEXT
2030 CLOSE
2040 RETURN
2050 ''------------- sub 10--------------------
2060 FOR K=BEG TO LAST
2070 A1(K)=A1(K)*10  :A1(K)=FIX(A1(K))/10
2080 A2(K)=A2(K)*10  :A2(K)=FIX(A2(K))/10
2090 A3(K)=A3(K)*10  :A3(K)=FIX(A3(K))/10
2100 A4(K)=A4(K)*10  :A4(K)=FIX(A4(K))/10
2110 A5(K)=A5(K)*10  :A5(K)=FIX(A5(K))/10
2120 A6(K)=A6(K)*10  :A6(K)=FIX(A6(K))/10
2130 IF A1(K)>A1MAX THEN A1MAX=A1(K)
2140 IF A2(K)>A2MAX THEN A2MAX=A2(K)
2150 IF A3(K)>A3MAX THEN A3MAX=A3(K)
2160 IF A4(K)>A4MAX THEN A4MAX=A4(K)
2170 IF A5(K)>A5MAX THEN A5MAX=A5(K)
2180 IF A6(K)>A6MAX THEN A6MAX=A6(K)
2190   IF A1(K)<A1MIN THEN A1MIN=A1(K)
2200   IF A2(K)<A2MIN THEN A2MIN=A2(K)
2210   IF A3(K)<A3MIN THEN A3MIN=A3(K)
2220   IF A4(K)<A4MIN THEN A4MIN=A4(K)
2230   IF A5(K)<A5MIN THEN A5MIN=A5(K)
2240   IF A6(K)<A6MIN THEN A6MIN=A6(K)
2250 IF A1(K) = A1MAX THEN M1=K
2260 IF A2(K) = A2MAX THEN M2=K
2270 IF A3(K) = A3MAX THEN M3=K
2280 IF A4(K) = A4MAX THEN M4=K
2290 IF A5(K) = A5MAX THEN M5=K
2300 IF A6(K) = A6MAX THEN M6=K
2310    IF A1(K) = AIMIN THEN N1=K
2320    IF A2(K) = A2MIN THEN N2=K
2330    IF A3(K) = A3MIN THEN N3=K
2340    IF A4(K) = A4MIN THEN N4=K
2350    IF A5(K) = A5MIN THEN N5=K
2360    IF A6(K) = A6MIN THEN N6=K
2370 NEXT
2380 RETURN
2390 '----------- sub 12-------------------
2400 FOR K=BEG TO LAST
2410 IF A1(K)>180 THEN A1(K)=A1(K)-360
2420 IF A3(K)<180 THEN A3(K)=ASS-A3(K)
2430 IF A3(K)>180 THEN A3(K)=360-A3(K)+ASS
2440 A5(K)=360-A5(K)+ASS
2450 A6(K)=360-A6(K)+ASS
2460 NEXT
2470 RETURN
2480 ''---------- sub 13 -----------------
2490   Z1=(LA1-BA1)*10 :Z1=FIX(Z1)/10
2500   Z2=(LA2-BA2)*10 :Z2=FIX(Z2)/10
2510   Z3=(LA3-BA3)*10 :Z3=FIX(Z3)/10
```

```
2510   Z3=(LA3-BA3)*10 :Z3=FIX(Z3)/10
2520   Z4=(LA4-BA4)*10 :Z4=FIX(Z4)/10
2530   Z5=(LA5-BA5)*10 :Z5=FIX(Z5)/10
2540   Z6=(LA6-BA6)*10 :Z6=FIX(Z6)/10
2550   W1=Z1/TT*10 :W1=FIX(W1)/10
2560   W2=Z2/TT*10 :W2=FIX(W2)/10
2570   W3=Z3/TT*10 :W3=FIX(W3)/10
2580   W4=Z4/TT*10 :W4=FIX(W4)/10
2590   W5=Z5/TT*10 :W5=FIX(W5)/10
2600   W6=Z6/TT*10 :W6=FIX(W6)/10
2610 RETURN
2620 ''------------ sub 14 -----------
2630 EEXT$=".tak"
2640 SKI$=EX$+NOME$+EEXT$
2650 OPEN"o",#1, SKI$
2660 PRINT  QTT,BCAA,BCAI,BCAR,LCAA
2670 PRINT  LCAI,LCAR,LCDMA,LCDMI,LCDMR
2680 PRINT  LCDNA,LCDNI,LCDNR,VAB,VIB
2690 PRINT  VRB,VAT,VIT,VRT,CA
2700 PRINT  CI,CR,VAMAX,VIMAX,VRMAX
2710 PRINT  VAMIN,VIMIN,VRMIN,BA1,BA2
2720 PRINT  BA3,BA4,BA5,BA6,LA1
2730 PRINT  LA2,LA3,LA4,LA5,LA6
2740 PRINT  A1VM,A2VM,A3VM,A4VM,A5VM
2750 PRINT A6VM,A1VN,A2VN,A3VN,A4VN
2760 PRINT A5VN,A6VN,W1,W2,W3
2770 PRINT W4,W5,W6,Z1,Z2
2780 PRINT Z3,Z4,Z5,Z6,TT
2790 PRINT TKL,TVM,TVN,VKA,VKI
2800 PRINT VKR,DKA,DKI,NOME$
2810 PRINT #1, QTT,BCAA,BCAI,BCAR,LCAA
2820 PRINT #1, LCAI,LCAR,LCDMA,LCDMI,LCDMR
2830 PRINT #1, LCDNA,LCDNI,LCDNR,VAB,VIB
2840 PRINT #1, VRB,VAT,VIT,VRT,CA
2850 PRINT #1, CI,CR,VAMAX,VIMAX,VRMAX
2860 PRINT #1, VAMIN,VIMIN,VRMIN,BA1,BA2
2870 PRINT #1, BA3,BA4,BA5,BA6,LA1
2880 PRINT #1, LA2,LA3,LA4,LA5,LA6
2890 PRINT #1, A1VM,A2VM,A3VM,A4VM,A5VM
2900 PRINT #1, A6VM,A1VN,A2VN,A3VN,A4VN
2910 PRINT #1, A5VN,A6VN,W1,W2,W3
2920 PRINT #1, W4,W5,W6,Z1,Z2
2930 PRINT #1, Z3,Z4,Z5,Z6,TT
2940 PRINT #1, TKL,TVM,TVN,VKA,VKI
2950 PRINT #1, VKR,DKA,DKI,NOME$
2960 CLOSE
2970 ''----------- sub 15 ------------
2980 KK=25*N+M4
2990 FOR I=1 TO N*M
3000 YA=VA(KK)
3010 YI=VI(KK)
```