Ski Jumping Flight:

A Kinematic Analysis of the Mid-flight

and Preparation For Landing Phases.

By

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Abstract

Competitive success in the sport of ski jumping is made possible through the optimal performance of jumpers during flight. While the flight phase has been the subject of several scientific investigations, there remain many questions concerning the optimization of this most important phase.

The purpose of this study was to identify and quantify specific kinematic variables of both the mid-flight and the preparation for landing phases of ski jumping flight. Secondly, the study sought to examine the statistical contribution of variables in both phases to the distance jumped. Finally, an attempt was made to develop a model which would provide a general view of the structure of the relationships among analyzed variables.

The subjects for this investigation were 50 highly skilled nordic combined competitors participating in the 1996 World Cup K-88 event. Fourty trials from the first round of competition were selected for inclusion in the data analysis.

The data for the 40 analyzed subjects was collected using two cameras mounted on Peak Performance Pan and Tilt Heads. The jumpers were taped as they passed through the field of view, from 55 to 85 meters on the jump hill. The Pan and Tilt hardware enabled the data to be collected over a wide field of view which resulted in the analysis of both the mid-flight and preparation for landing phases. Values for the distance jumped and the inrun velocity were collected from the official results printed by the FIS competition committee.

The Peak Performance 3D Video Analysis System was used to extract the horizontal and vertical coordinates for a 19 point segmental model. The center of mass was calculated for the model, which included the masses of skis, helmet and boots. Data

was smoothed and processed to compute linear displacements and velocities and angular displacements in the three planes of motion. Statistical treatment of the raw kinematic data was performed using the appropriate computer programs from SPSS.

Correlation analyses were conducted on the variables of the mid-flight and preparation for landing phases to determine the strength of any relationships between the selected variables and distance jumped. Both full and stepwise regression analyses were conducted on the two analyzed phases of flight to assess the predictability of the dependent variable, distance jumped. Also, a varimax rotated factor analysis was developed for each of the mid-flight and preparation for landing phases to examine the complex intercorrelations between independent variables.

The results of the study revealed the kinematic variables that are associated with increasing the distance jumped. A general model of the relationships between independent variables and their contribution to the distance jumped gave insight into the traits that may be optimized in order to improve ski jump performance. The results of the mid-flight phase suggested that, in order to increase distance jumped, athletes should attain a compact, forward flight position with a small angle of attack, optimize previous movements in order to achieve a high flight curve, and maximize the inrun velocity. The preparation for landing results indicate that the best jumpers had an open flight position and a greater negative vertical velocity. Flight positions in both analyzed phases were observed to have a large effect on aerodynamic factors and the distance jumped.

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Chapter 1

Introduction

Ski Jumping is a very complex skill which consists of four main phases which are the inrun, take-off, flight and landing. The flight can be further subdivided into the transition into flight, mid-flight and preparation for landing. The phases of the ski jump have typically been studied separately for the sake of simplicity. However, it is important to note the inter-dependence of each of the phases of ski jumping, that is, success in any phase depends on the previous phase. The entire skill is evaluated subjectively by style judges, and objectively by distance measurement. Points from each of these aspects are tabulated to give the final jump score. The competitive format of ski jumping involves two rounds of jumping, with only the top 35 jumpers qualifying for the second round. The closely related sport of nordic combined includes two competitive rounds of jumping, followed by a cross country ski race the following day with start order and intervals determined by the ski jump performance.

Researchers (Jost, 1995; Vaverka, 1995; Virmavirta & Komi, 1991, Watanabe & Watanabe, 1993) have analyzed many aspects of this complex skill using force analysis techniques, electromyography, cinematography and videography. Wind tunnel testing has also played an important role in determining optimal flight positions and posture. Results from the wind tunnel analyses have been used as a basis for computer modeling which enables the prediction of distance jumped (Remizov, 1984; Luhtanen, 1995). These studies have done much to guide coaches and jumpers in their attempts to attain effective flight positions that maximize the potential lift while minimizing drag.

The quality of jumping has been steadily improving over the past 70 years, which may be partially attributed to the ongoing research into ski-jumping technique. Kinematic analysis has helped the researcher to observe and examine the flight parameters in a competitive situation and to confirm the theoretical research. However, until recently, only two dimensional kinematic analyses had been documented. Technical advances in the collection and analysis of three dimensional kinematic data have allowed this information to be collected more easily and accurately in the competitive environment.

Statement of Purpose

Purpose

The purpose of this study was to first identify and quantify in three dimensions the specific kinematic variables of both the mid-flight and the preparation for landing phases. Secondly, the study sought to examine the statistical contribution of variables in both phases to the distance jumped. Finally, the study attempted to develop a model which would provide a general view of the structure of the relationships among analyzed variables.

Rationale

The evolution of ski jumping technique has led to the V-Style flight technique, in which the skis are spread apart at the tips in the frontal plane. Several kinematic analyses of ski jumping flight have been performed using two dimensional analysis techniques (Jost, 1994; Puumala, 1995). While valuable information was gleaned regarding the primary movements of the flight phase in the sagittal plane, there exist some limitations to the application of these results. Movement of the skis in the frontal plane has warranted the analysis of ski jumping flight in three dimensions. The author is aware of only one study that analyzed the flight phase of ski jumping in three dimensions (Jost, 1995). This three dimensional analysis was conducted on a K180 ski jumping hill, rather than an Olympic size hill (K90 or K120). With large differences in speed and aerodynamic qualities, it is believed that critical differences may exist in the optimal technique necessary to achieve a successful performance on each size of hill.

The kinematics involved in the final stage of flight prior to landing have been speculated on by several authors (Virmavirta & Komi, 1991; Arndt, Bruggemann, Virmavirta & Komi, 1995), but have never been directly measured in a competitive setting. It is believed that movements performed during the preparation for landing may be optimized by jumpers in order to maximize the total distance jumped. Variables thought to be important to the performance of the preparation for landing were measured and analyzed to test previous assumptions concerning the final part of flight.

Limitations

The study is limited by the following factors:

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

2. The influence of weather conditions on the jumpers performance.

3. The use of estimated body segment parameter values (Plagenhoef, Evans & Abdelnour, 1983) in the determination of the center of mass.

4. The calculation of three dimensional coordinates from the Peak Performance calibration procedure.

Delimitations

The investigation is delimited to:

1. The data collected on ski jumps performed by 50 first round competitors, during the World Cup in Steamboat Springs, Colorado on December 11, 1996.

2. The analysis of recordings made by two cameras set up to view the mid-flight and preparation for landing phases between the 55 and 85 meter marks on the landing hill.

3. The analysis of selected flight phase parameters (a.skier-ski system, b.skier-ski system and flight direction and, c.velocity and flight direction) calculated at three points for each of the flight and preparation for landing phases.

4. The relationship of specific flight and landing parameters to the distance jumped.

Definition of Terms

Inrun Phase

The first phase of a ski jump, which begins when the jumper leaves the gate and ends when the first impulse is made for the take-off movement. The primary purpose of the inrun is to generate maximum velocity over a set distance. The second objective is to create an optimum body position for the subsequent take-off

Take-Off Phase

The second phase of a ski jump, which begins when the first impulse is applied and ends the moment the body's line of gravity is perpendicular to the take-off area (Baumann, 1979). The take-off is defined as the movement which dictates the transition from the inrun phase to the flight phase. The purpose of the take-off is to create conditions for assuming an ideal flight position as quickly as possible, while maximizing horizontal and vertical displacement.

Flight Phase

The third phase of a ski jump, the flight phase begins when the jumper has moved their center of mass over the skis, which have spread to a wide V position. The phase concludes when the jumpers skis make contact with the landing hill. The primary purpose of this phase is to maximize distance jumped by achieving the most aerodynamically efficient flight position. This phase can be subdivided into the: transition into flight, mid-flight and preparation for landing.

Transition Into Flight

The first subphase of ski jumping flight. The transition into flight begins when the take-off phase ends (0-2 meters), and finishes when a stable flight position is achieved, about 10-15 meters after the end of the take-off (Vaverka, 1991). The purpose of the flight transition is to achieve the greatest possible lift while moving the center of mass forward into an aerodynamically efficient flight position.

Mid-flight

The second stage of flight in ski jumping. The mid-flight begins when the jumper has achieved a relatively stable position in the air with the center of mass in a forward position, relative to the foot. Mid-flight ends when the jumper begins moving the center of mass backward in order to move into a safe landing position.

Preparation for Landing

The final part of the flight phase, where the jumper opens up the angle of the body and the skis, moving the center of mass backward towards the feet and prepares to execute a safe, stylish landing.

Lift

A force which acts on the skier-ski system perpendicular to the drag force or direction and tends to increase the height of the flight path.

Drag

A force acting on the skier-ski system in a direction opposite to the direction of motion and tends to decrease velocity.

Landing Phase

The fourth and final phase of a ski jump. The landing phase begins the instant the skis make contact with the snow and ends when the jumper has moved into a stable position on the landing hill.

Telemark Landing

A landing position where one foot is placed forward of the other with the knees bent to absorb the force. The telemark landing is considered more stylish than a landing

executed with the feet together and if properly performed, receives maximum points from the style judges.

V Style

V Style is a flight technique where the skis are placed in a wide position in the frontal plane through eversion and external rotation of the hips and knees. The skis are together at the tails and apart at the tips, thus the name "V style". This style of flight has recently come into popularity and is assumed to give greater lift, and therefore, greater distance than the traditional technique, with the skis parallel.

Angle Of Attack

The angle between the longitudinal axis of a jumper, taken as a line drawn from the shoulder to the ankle, and the direction of the air flow (Jin et al., 1995).

Normal Point (P Point)

The P point of a ski jumping hill is the point on the landing hill where the slope increases to a value between 37 and 41 degrees. The increase in slope is to facilitate safe landings of the jumpers by following the parabolic flight curve. The P point is marked with a blue line. (See figure 1.)

Critical Point (K Point)

The K point of a jump hill is the point where the slope of the landing hill begins to decrease from the steepest part of the hill, where it is safest to land. Landing past the K point results in larger ground reaction forces to be absorbed by the jumper. These increased forces can result in dangerous landing conditions, and are controlled by limiting the inrun velocity so that the best jumper is reaching distances matching the K point. The K point is always marked by a red line on the landing hill. (see figure 1.)

K 90 and K 120

These two sizes of ski jumping hills are generally standard sizes for World Cup and Olympic ski jumping competition. The size of hill is denoted by the critical point, which is measured by the distance from the take-off to the K point, where the hill begins to flatten out.

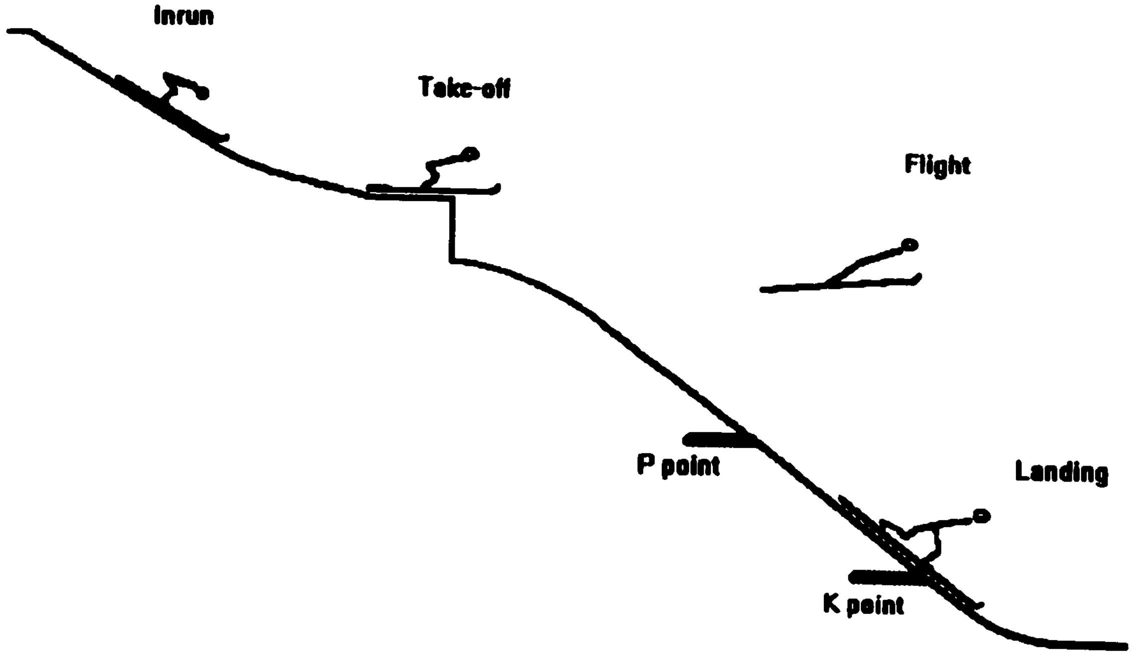


Figure 1. Structure of a Ski Jump With Associated Phases.

Chapter 2

Review Of Literature

The sport of ski jumping has evolved a great deal over the past seventy years, due partly to the scientific study of technique. Scientific investigations have been performed from the time when the sport involved jumps of 50 meters on wooden skis with leather bindings to the sport of today where the athletes use technically advanced equipment to jump as far as 200 meters.

Olympic and World Cup ski jumping normally involves competition on hills designated as 90 meters or 120 meters. These are the standard hills for competition, which are measured by the distance from the end of the take-off platform to the critical (k) point on the hill. There are also six hills in the world much larger than the standard competition hills and are referred to as ski flying hills. The design of these hills are much the same as the standard hills, but the critical (k) point is up to 180 meters from the take-off. It is on hills such as these that jumpers have reached distances of over 200 meters. However, the speeds used on these hills are much faster and only the very best jumpers usually compete on them.

Both the equipment used by the athletes and the hills they ski on are regulated by the Federation Internationale de Ski (FIS). FIS is the international committee that ensures the use of standard equipment for fairness and standardized hills for safety of the skiers. Research is regularly conducted regarding the regulations which are enforced by the FIS (Muller, 1994).

A Breakdown of Ski Jumping Into Phases

The four main phases of ski jumping can be further subdivided into seven specific phases; the inrun, preparation for take-off, take-off, transition into flight, mid-flight, preparation for landing and landing (Vaverka, 1987). In order to simplify the skill of ski jumping, coaches typically break a jump into these phases for the purpose of analyzing and teaching technique. Although phases can be studied independently, it is very important to understand the interdependence of each phase. In describing the optimization of ski jumping, Denoth, Luethi and Gasser (1987) stated that "all phases have a great influence on the jumping distance, and ... every stage of the jump has its consequences on the subsequent phases." (p. 414) For example, difficulty in the inrun phase such as being pulled back by the centrifugal force of the curve of the slope will make it almost impossible to execute an effective take-off movement (Campbell, 1990).

Inrun and Preparation for Take-off

The purpose of the inrun phase is to maximize velocity by moving down the initial slope in an aerodynamically efficient position. The second objective is to maintain a position from which an effective take-off movement can be executed. In terms of aerodynamics, the inrun is a low position in order to reduce the surface area of the front of the jumper and results in minimal turbulence (Campbell, 1990). This inrun position was first researched by the French national ski team in a wind tunnel experiment, performed in 1959. The results of this study produced the position referred to as the French 'egg position' in which the body is tucked into an ovoid position (Ward-Smith and Clements, 1982). The main difference between the common inrun position of today and the French 'egg position' is that the hands are now held straight back and resting on the hips. This 'hands back' position came into popularity just before the 1980 Olympics in Lake Placid (Watanabe, 1989).

As the jumper moves into the transition curve of the inrun, the centrifugal force tends to push the jumper backward and down, so that the center of mass moves back behind the center of the foot. The jumper opposes any forward or backward movement in the inrun, because any movement back will place the skier in an unfavorable position for jumping and will decrease the effectiveness of the take-off movement (Campbell, 1990).

The forces placed on the ski jumper while in the inrun often results in the center of mass moving back relative to the feet, when it should ideally be stable and ready to move forward very quickly during the take-off phase. It is the best jumpers then that are able to maintain an ideal position that optimizes aerodynamic factors as well as maintaining a forward position to lead into the next phase of the jump.

Take-Off

The take-off is considered to be the most critical phase of the ski jump performance, as it has the greatest effect upon the quality of flight and therefore, the distance of the jump. An effective take-off involves moving the center of mass into a forward position, while increasing both the vertical and horizontal velocities.

Campbell (1990) describes the objectives of the take-off as being:

1) to give the jumper-ski system a maximum normal (vertical) velocity,

2) to produce a favorable body position at the jumps edge, and

3) to provide an initial turning moment or angular momentum for the forward rotation of the body over the skis immediately after take-off.

Over the past 20 years, numerous kinematic studies have been conducted on the take-off phase (Campbell, 1979; Vaverka & Janura, 1994; Shao-Ming, 1994;). Each of the studies used two dimensional film or video analysis to quantify the kinematic variables and their optimization in accord with the distance jumped. A few studies measured kinetic variables via force platforms embedded under the take-off platform, in combination with measuring two dimensional kinematic characteristics (Vaverka, Janura, Krskova, Elfmark & Salinger, 1992; Virmavirta & Komi, 1993).

Vaverka et al. (1996) described the contradictions found in existing relationships between take-off parameters and the criterion variable, distance jumped. While it has been repeatedly noted in practice that the take-off is the most important phase in determining the success of a jump, the applied kinematic research does not support this. The disparity is explained by the multifactor theory of the take-off, in which the optimization of the take-off factors and individualization of the take-off parameters have been defined (Vaverka et al., 1996). A general model for the execution of the optimal take-off can not be defined and is illustrated by the significant intraindividual (between subject) differences on the take-off. It is important in an applied coaching setting that the trainer understands that there is no "correct" way of executing a take-off for all jumpers; each jumpers' take-off needs to be developed individually with the goal of optimization.

All factors are important, but generally the maintenance of a forward position during take-off should be emphasized. The forward position is directly related to a lower leg angle, which should be kept as small as possible throughout the movement (Campbell, 1990). Most coaches believe the best take-off angle to be 45 degrees or smaller (Watanabe, 1989). In practice, this requires the jumpers to have a good deal of ankle flexibility to make this position both possible and comfortable. Some of the research refers to the forward position as having the weight in front of the heel during the inrun and moving the center of mass of the body in front of the point of support during the take-off. This movement of the center of mass creates forward momentum which brings the jumper into an effective flight position (Pulli, 1989). Another critical factor of the take-off is the timing. It has generally been agreed upon among coaches and researchers that the best take-off is performed closest to the edge of the jump and over a very short time period (0.2 to 0.5 seconds) (Harkins, 1990).

Vaverka (1991) published a study that analyzed the take-off phase by measuring dynamometry of two take-off factors, vigor and accuracy and their effect upon length of jump. Force platforms were installed in the last 6 meters of the take-off on a summer jump hill covered in plastic. The study was performed during a competition on the K90 hill in Frenstadt, Czech Republic. Vigor can be defined as speed of the take-off movement, or "the result of the jumper's effort put forth on the last 6m distance from the jump edge" (Vaverka, 1991, p. 152). Accuracy of take-off is measured by the distance away from the edge of the jump that the take-off movement is completed. Through statistical analyses of the kinematic variables, it was found that a positive correlation exists between take-off vigor and accuracy. The percentage of variance in jump length attributed to by these factors was 21 percent. Approach velocity also added another 10 percent to the variance in distance. These factors were determined to be very important and may serve as a basis for identifying optimal combinations of parameters that will contribute to the overall success of the jump performance (Vaverka, 1991).

The complexity of the take-off results in it being a very difficult phase to coach. It is up to the coach to have a thorough knowledge of the importance of each factor that contributes to a good take-off It becomes more difficult to detect errors when coaching elite jumpers, due to the high speed of the movement.

Flight

Maximizing the flight distance is the general objective of all of the other phases of ski jumping. There are, however, many independent factors of the flight phase which can have a large effect on the success of the jump. While the take-off is generally considered the most crucial phase of a jump, this assumes that the jumper has mastered the skill of flying. For the unskilled jumper, mastering the skill of flight technique can drastically improve results (Campbell, 1990).

The first and most important question concerning flight technique is one of ideal positioning. Flight position was first studied by Strauman in 1927, in order to experimentally assess the most effective position. In a pioneering experiment, a model of a ski jumper in a windtunnel was used to measure the lift and drag components for different flight configurations. Strauman pointed out that the trunk should be bent forward in order to achieve a larger lift component and to minimize the drag component (Watanabe, 1989). Knowledge concerning optimal flight has increased since this early experiment. Much more recent research has been done to describe the precise angles and position for the ideal flight (Tani & Iuchi, 1971; Remizov, 1984; Pulli, 1989). While theoretical positions have been generally accepted as being valid, not a great deal of research has been done to confirm these values in a practical setting.

Research conducted on describing an ideal flight position has focused on defining the position in which lift is greatest, while drag is minimized. However, this is a converse relationship because, as lift increases, there is a proportional increase in drag (Campbell, 1990). The key to this position is the lift to drag ratio. A high lift to drag ratio is indicative of the lift being greater than drag, therefore being an efficient flight position. A low lift:drag ratio indicates a larger drag force than lift, which results in a much shorter jump distance (Campbell, 1990).

Although the determination of a high lift to drag ratio sounds workable in theory, it is complicated by the fact that the flight position is not a constant one and can be subdivided into three stages: 1) the transition into flight, 2) mid-flight, and 3) preparation for landing. Ideal positions for two of the three sub phases have been described by Remizov (1984). The optimal transition into flight phase is described as having the best aerodynamic efficiency to maintain initial velocity from the take-off. Towards the end of flight, the jumper begins to open up the flight position to increase the lift component. The benefit of the extra lift is thought to outweigh the reduction in velocity due to the drag at the later stage of flight.

Flight Transition

The flight transition phase can be described as the period of time after the skis have left the snow of the take-off platform until the jumper achieves a forward, stable flight position. During this phase of the jump, the athlete spreads the skis into the "V" style position. Schwameder (1993) indicated that the "V" technique enables jumpers to assume a compact body configuration in early flight and consequently a more beneficial aerodynamic position. The importance of the flight transition phase was emphasized by

Arndt, Bruggemann, Virmavirta and Komi (1995), who found that the motions of the ski jumper in early flight were of greater importance to the final result than the take-off parameters. They did recognize, however, that this may have been the result of the sample demonstrating a very uniform technique on take-off while exhibiting many differences during the transition. Other factors described as being critical in the flight transition phase are the velocity and rotation of the skier-ski system. Vakerka and Janura (1994) described the best jumpers as those displaying the highest horizontal velocity, the least decrease in the height of the flight curve, a tendency to a progressive forward lean, and a faster rotation forward over the skis. These factors result in the jumper quickly achieving an aerodynamically efficient flight position.

Mid-Flight

The investigation of Tani and Iuchi (1971) built on the early work of Strauman (1927) which demonstrated the advantage of a forward lean during flight. Through wind tunnel testing performed on a wooden model of a ski jumper, the researchers were able to define equations of the flight path, as well as optimal flight positions to maximize lift and minimize drag. They also recognized that while a constant flight position is not practical, they were able to define an optimal angle of attack. It also became evident from the results of this study that the arms should be held close to the body, rather than forward, as had been previously accepted.

Further wind tunnel studies were carried out by Ward-Smith and Clements in 1982 on a scaled model of a ski jumper. The researchers found that an ideal angle of attack would be 8 degrees, if it were possible to avoid tumbling at such a low incidence angle. A more practical value of 25 degrees was presented as being an optimal angle of attack for a ski jumper in free flight (Ward-Smith and Clements, 1982).

The research of Remizov (1984), added to the work of Tani and Iuchi, by describing in greater detail how the optimal angle of attack should be altered during the flight in order to achieve the greatest distance. Remizov noted that, it had always been assumed that a constant angle of attack which corresponded to the maximal aerodynamic quality, that is the maximum lift to drag ratio, should be maintained. However according to his calculations this would result in a decrease of 13 meters at an initial speed of 30 meters/second as compared to the optimal trajectory (Remizov, 1984). A difference was also seen between the optimal angle of attack during the first part of flight of large and small hills. This was attributed to an increased drag with greater speed on large hills (27-33 m/sec for large hills, compared to 20-25 m/sec for small hills). For this reason, the optimal angle of attack was defined as being 30 degrees for smaller hills, compared with 15- 23 degrees for the early flight on large hills.

The results of Remizov's calculations also emphasized the substantial influence of the ski jumpers dimensions on the aerodynamic quality. It was noted that jumpers of small weight and with a flattened body with a large frontal area would be ideal for flight. These type of body proportions provide less drag during the early flight phase and greater lift towards the second part of flight (Remizov, 1984). Remizov's conclusions were that the angle of attack should be small during the first part of flight, in order to reduce drag. As the flight progresses into the second part, the angle of attack should decrease in order to increase lift. It was found that the lifting property was more important than minimizing the drag effect in the later stages of flight.

Remizov's (1984) earlier mathematical modeling study seems to contradict the more recent work of Pulli (1989). While Remizov suggests that the optimal lift position should occur during the second part of flight, Pulli indicated that the greatest lift position, characterized by a more open trunk angle, should be performed during the transition into flight phase. He recommends that movements in the second part of flight should focus on achieving the best aerodynamic position in order to reduce drag. While it is still not clear as to which optimal model of lift and drag is more effective, recent research suggests that the aerodynamic drag is minimized in the middle part of flight (Puumala, 1995). It would seem that, if a position of greater lift were used, it is past the middle stage of flight. Ski jumping requires the optimization of many factors, with many individual differences between jumpers. In other words, a jumper with good lift in the first part of flight, may jump the same distance as a jumper achieving maximum lift in the second part of flight.

Comparisons of three different flight styles were made through wind tunnel studies and computer modeling by Jin et al., in 1995. The three styles were defined as classic style (with skis parallel), "V" style (with ski tips spread apart) and flat "V" style (same as "V" style, except more flat in the saggital plane). While it may be questionable whether there is an actual distinction between two different types of "V" style jumping in a competitive setting, the models are useful for comparison purposes. One limitation of the study was that a rigid model was used which enables the determination of the lift and drag characteristics of the jumper, but does not account for postural changes during flight.

Results of the comparative analysis showed that the flat "V" style was more efficient, creating less drag than the "V" style, but much greater lift than the classic style. The researchers recommend that the jumper assume the flat "V" style, in particular during the flight transition, and increase the angle of attack to the more open "V" style position in late flight to maximize the lift component (Jin et al., 1995).

Another study which incorporated wind tunnel results into a computer simulation program was performed by Luhtanen in 1995. Similar to Jin et al. (1995), this method enabled the prediction of distance jumped through the manipulation of key flight variables. The method used to collect the wind tunnel data make this study noteworthy. Nine high calibre Finnish jumpers were suspended in a wind tunnel with harnesses, which enabled them to select the most aerodynamic flight position. The method accounts for the minute postural changes made by the jumper in the air. Through entering into the computer program both the individual aerodynamic qualities of each jumper and the specific variables concerning the hill and wind conditions, Luhtanen was able to predict distance jumped quite accurately. An interesting additional finding was the large influence wind conditions has of the flight performance of the jumpers, which is greater for the lighter jumpers than the heavier ones (Luhtanen, 1995). The only way to eliminate this extreme influence (which can often be dangerous) is to construct wind screens around the ski jump itself.

In the past several years, kinematic analyses have been performed on the mid-flight phase of ski jumping and have confirmed much of the previous wind tunnel and mathematical modeling studies (Jost, 1995; Puumala, 1995). Jost (1995) performed one of the first three dimensional analyses of the flight phase at the world ski flying championships. The study used three dimensional video analysis techniques to calculate parameters through the middle part of the flight phase. The better jumpers were found to fly at a smaller angle and were more inclined forward during flight. A small angle between the "body-bow-line" and the skis was significantly correlated to distance jumped. The analysis determined that the angle between the skis was greater for the best jumpers in the XZ plane. The results from Jost's ski flying analysis were compared to his previous three dimensional study (Jost, 1994) of the flight parameters of a 120m jump and found to be very similar. The comparison between flight parameters of the ski jump flight and ski flying flight is important in order to show that the flight qualities are similar between ski flying (180M) and standard competition hills (90m and 120m).

Perhaps the most interesting finding of Jost's 180m ski flying study, was that of an increase in the horizontal velocity observed between the first and last analyzed parts of the phase. This tendency, which was only displayed by the best jumpers, had not been previously described in the literature. Correlations were insignificant for horizontal velocity as a whole, but were not performed on the change in velocity. It is felt that this result may have a tremendous impact on the competitive success of the jumpers during the flight phase. A gliding effect was the explanation given for this increase in horizontal velocity seen in the ski flying kinematic analysis (Jost, 1995). The two dimensional mid-flight analysis performed by Puumala in 1995, confirmed the change in velocity findings of

Jost (1995) and suggested that the movements associated with the increase should be optimized increase may be optimized in the future in order to increase the distance jumped.

<u>Preparation for Landing</u>

In order for a jumper to be able to move into the landing they must stop their forward rotation and create a backward moment by increasing the forward lean and trunk angles and decreasing the arm angle (Campbell, 1990). However, changing the optimal flight position into this landing motion too early will certainly decrease the possible distance of a jump. Virmavirta and Komi (1991) performed a study that described the electromyographic activities in the muscles of the legs throughout the entire jump. They observed an early activation of the muscles used for executing the landing and speculated that bending the knee too early before landing could be because the jumper is afraid of maintaining the optimal flight position for as long as possible. Another possibility may be that preparation for a safe and smooth landing requires a fairly long time to execute. Similarly, Arndt et. al. (1995) referred to the psychological difficulty of maintaining an aerodynamic position when the skier is only about 1 meter above the ground prior to landing. They also infer through qualitative observation that some jumpers are able to add an extra 5 meters at the end of the flight by maintaining an efficient flight position longer and thus delaying the movement to land. The speculative nature of these findings illustrates the need for quantitative research on the possible advantages to be gained during the preparation for landing phase.

The lack of research on the preparation for landing phase has raised many questions concerning performance. Jumpers and coaches have been left to decide for themselves how to best perform the movements from flight to landing without sacrificing crucial distance and style points.

Landing

The landing phase of a ski jump is very important for several different reasons. The first is safety - a stable landing helps to prevent a fall and completes the jump. The second reason is that by delaying the landing, by not moving from the flight position into a landing until the last possible moment, the jump length will be maximized. Lastly, but also very important, is the execution of a good telemark landing, which will ensure good style points from the judges.

Pulli (1989), describes the forces acting on a ski jumper upon landing as 1) gravity with a component parallel to the landing slope, 2) an impact force vertical to the surface, 3) air resistance and 4) frictional force. These forces are easily overcome under normal conditions. However one condition that makes the forces difficult to absorb, is the slope of the landing hill. Between the P and K points, the angle of the landing hill is constant and optimal for landing. Below and above the P and K points the slope is less steep and much more difficult, and even dangerous. For this reason, speeds in the inrun are monitored closely to prevent any jumper from landing too far past the K point.

The Structure of Relationships Between Phases

In the past, few investigators attempted to measure kinematic variables and their interelationship in the competition setting. However, recent technological developments in video measurement and analysis equipment have improved the accuracy of the quantification of kinematic data. Dr. Frantisek Vaverka, of the Czech Republic, has been a leader in the area of kinematic analysis of ski jumping. Through the cooperation of research teams from Czech Republic, Slovenia and Canada, Vaverka focused on the kinematic relationships between the phases of the entire jump (Vaverka, McPherson, Janura, Elfmark & Puumala, 1995).

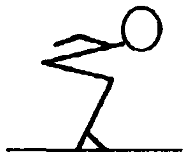
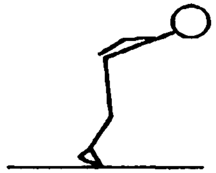
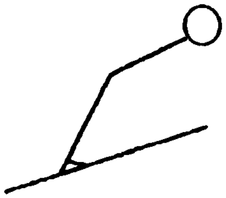
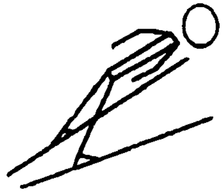
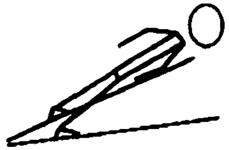
A two dimensional kinematic data collection was completed in Innsbruck, Austria, in which the variables of the inrun transition, take-off, flight transition and two stages of mid-flight were quantified.

A factor analysis was performed on the data collected in Innsbruck, which included variables from each of the main phases of the ski jump. Individual factors and the respective rotated factor loadings were developed for each of the phases in order to shed light on the groups of correlated variables and their influence on the distance jumped. The results of the communality values for each of the analyzed phases addressed the interdependence of the phases of ski jumping. The preliminary results of this longitudinal study indicate that the percentage of the variance explained of distance jumped, increased from 30% to 40% in the take-off and transition phases, to 85% during the mid-flight phase (from 60m - 75m in this particular study). Vaverka's study did not, however, attempt to assess the contribution of the preparation for landing phase to the distance jumped. This final stage of flight has only been speculated on in the literature and has never been studied kinematically.

Table 1

FACTOR ANALYSIS OF DIFFERENT SKI-JUMPING PHASES AND THE CONTRIBUTION OF DIFFERENT PHASES TO THE LENGTH OF JUMP INNSBRUCK 1995, K120

(adapted from Vaverka et al., 1995)

SKI JUMPING PHASES		 INRUN	 TAKE-OFF		 TRANSITION				 FLIGHT I			 FLIGHT II		
Distance From Edge (m)		-18	-4	0	1.8	5.6	6.5	12.5	15	20	25	59	68	75
Commun-ality Of Jump Length	CZE (2D)	0.32	0.33	0.19		0.36								
	SLO (2D)				0.53		0.30							
	(3D)						0.44	0.32						
	CAN (2D)								0.17	0.42	0.45	0.73	0.83	0.87

Chapter 3

Experimental Procedures

The methods and procedures to be used in the examination of the problem are described under the following headings:

1. Pilot Study
2. General procedures
3. Video-taping procedures
4. Data analyses
5. Statistical procedures

Pilot Study

A pilot study was performed in January 1995, by the principal researcher, as part of a cooperative study headed by Dr. Frantisek Vaverka of the Czech republic. The purpose of the two dimensional study was to investigate selected variables of the flight phase and gain insight on possible relationships with the distance jumped. Pilot data was collected on jumps completed on the K110 ski jump in Innsbruck, Austria. The annual world cup competition is the third meet in the Springertournee Four Hills competition which takes place in Austria and Germany. The data collection site was ideal for the analysis and the sample included the best jumpers in the world.

Results of the pilot study were used to help select variables for inclusion in the present analysis. In addition to laying the groundwork for the further study of ski jumping flight, the data was used as a part of a larger collaborative study to assess the long term changes in ski jumping technique and the contribution of analyzed phases to the distance jumped.

The results of the two dimensional analysis confirmed results from many of the previous wind tunnel studies and mathematical modeling studies. The best jumpers were observed to flatten out their trunk and thigh angle, as well as maintain a smaller ski and leg angle through the analyzed phase. The trunk and ski angle was also smaller for the best jumpers, and got progressively smaller, indicating a further movement of the trunk towards the skis. The best jumpers were also seen to maintain the smallest angle between the leg and flight direction. These small flight angles observed in the most successful jumpers were thought to produce a more aerodynamic flight position. An increase in horizontal velocity was noted in the mid-flight by the best jumpers, and was thought to be a result of this more compact flight position. As this increase in horizontal velocity was only seen in the best jumpers, it was suggested that it may play an important role in optimizing flight performance.

A subsequent two dimensional analysis was performed during the 1996 Intersport Springertournee event, held in Bischofshofen, Austria. Data is presently being analyzed for the inclusion in a larger collaborative study. The data from this analysis appears to support the results found in the Innsbruck study.

General Procedures

Sample

The subjects analyzed in the present study were 40 of the top athletes who participated in the 1996 Steamboat Springs Nordic Combined World Cup. Of the 50 athletes who competed, 40 trials met criteria in terms of quality of picture and suitability of field width and were selected for further analysis. The first competition round was analyzed. All of the jumpers were males between the ages of 16 and 30 years.

Data Collection Site

The experimental site was the Howelsen Hill K88 meter ski jumping hill in Steamboat Springs, Colorado.

Protocol

Each athlete was video taped during the first competitive round of the world cup competition. The 50 competitors had been selected to compete at the world cup level through qualifying in previous national and international competitions. The second and final round of competition was also taped, but not analyzed in the present study.

Video-Taping Procedures

The data used for this analysis was collected using two Panasonic digital video cameras (Model CL-350), equipped with high speed shutters. Movement was recorded at a rate of 30 frames per second. Each frame was subsequently sampled at 60 Hz using the Peak Performance 3d Analysis System. The high speed shutter was set according to light conditions in order to enhance the clarity of the image. Two cameras were leveled and positioned with focal paths at a 90 degree angle to one another. The cameras were positioned on one side of the path of motion as presented in Figure 2. The meter markers on the opposite side of the landing hill served as reference points. The field width was 30 meters in total, from the 55 meter mark to the 85 meter mark on the landing hill. Each athlete was filmed through the entire field width using pan and tilt hardware (Peak Performance Technologies, Englewood, CO.) The three dimensional space was calibrated using six calibration rods, filmed in the field following the competition.

Data Analysis

The techniques to be used for analyzing the data obtained from video-taped records are described under the following headings: a) video analysis procedures, b) data smoothing and c) variable selection.

Video Analysis Procedures

Each of the 50 jumpers competing in the first round of competition were digitized using the Peak Performance 3D Video Analysis System located in the Biomechanics Laboratory at the Lakehead University Sports Institute. Using a 19 point segmental model adapted to include skis, the anatomical endpoints were digitized for each jumper on every frame from 50 meters to 60 meters for the mid-flight analysis and for 12 frames prior to landing for the preparation for landing analysis from each of the two camera recordings. Following digitization, the Peak 3D System software applied the direct linear transformation method to reconstruct the three dimensional coordinates. The software calculated the centers of mass of body segments (Plagenhoef et al., 1983), as well as the linear and angular displacement, velocity and accelerations. The average mass of the skis, helmet and boots (12.5 Kg) were also included in the center of mass calculation, to most accurately represent the segmental mass characteristics of the jumpers.

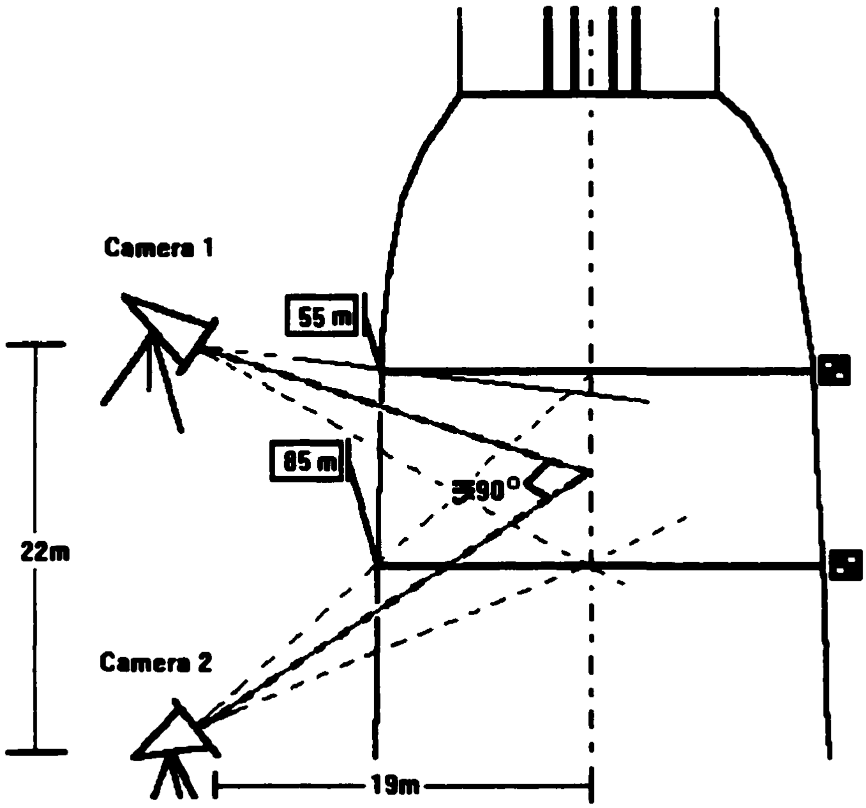


Figure 2. Diagram of filming site.

Data Smoothing

The data was smoothed using a second order Butterworth-digital filter in order to remove any noise from the signal. For each trial, the Peak Performance Smoothing Software selected the optimal cut-off frequency for each of the segmental end points (Peak Performance, 1995).

Variable Selection

The variables selected to be included in the study were generated through consultation with ski jumping experts and a review of the relevant literature. The data can be divided into three separate subgroups of related variables as follows: i) skier-ski system, ii) skier-ski system and flight direction and iii) velocity and flight direction. Variables in the three subgroups were analyzed at three different points during the analyzed phase for mid-flight (50, 55 and 60 meters). The preparation for landing analysis included two of the subgroups of variables: i) skier-ski system, and iii) velocity and flight direction. The two groups of variables were measured at twelve frames prior to landing and also at six frames prior to landing. Variables were measured at twelve and six frames prior to landing as it was seen that jumpers were generally beginning their move into the landing at twelve frames prior to landing. At six frames prior to landing, all jumpers were well into their landing movements. Three extra variables were recorded including the inrun velocity ($Velocity_{IR}$), the distance jumped (Distance), and the change in horizontal velocity of the center of mass ($\Delta Velocity_H$). The first two extra variables were obtained from the official results printed and distributed by the FIS, and the horizontal velocity change was calculated by subtracting the $Velocity_H$ at 50 meters from $Velocity_H$ at 60 meters for mid-flight. The change in horizontal velocity for the preparation for landing analysis was measured as the difference in horizontal velocity from 12 frames prior to landing to the heel contact of the landing itself.

Skier-ski system

The three variables used to describe the skier-ski system in the XY plane included the trunk and thigh angle ($Trunk/Thigh_{XY}$), the ski and leg angle (Ski/Leg_{XY}), and the trunk and ski angle ($Trunk/Ski_{XY}$). The variables analyzed in the XZ plane included the angle of the skis to each other ($Skis_{XZ}$) and the angle of the legs ($Legs_{XZ}$). The angles of these variables were calculated by the Peak Performance Video Analysis System software. See Figure 3a and 3b.

Skier-ski system and flight direction

The angles of the skier-ski system and flight direction were defined as the angle between the ski and the direction of flight (Ski/Dir$_{XY}$), the angle between the leg and the direction of flight (Leg/Dir$_{XY}$) and the angle between the trunk and the direction of flight (Leg/Dir$_{XY}$). These three variables related the skiers flight position directly to the path of motion. Also known as the angles of attack, the skier-ski system and flight direction variables were analyzed only for the mid-flight analysis. The direction of flight was calculated using the velocity data which is presented in the next section. See Figure 4.

Velocity and flight direction

The velocity and flight direction variables included the three components of velocity; the horizontal velocity (Velocity$_H$), the vertical velocity (Velocity$_V$), and the resultant velocity(Velocity$_R$). The velocity variable was calculated by the Peak Performance Analysis System for each frame and taken from the center of mass of the skier. Other variables calculated included the angle of the flight curve (Flight α), and the distance of the center of mass to the landing (Displ. c/m). For the mid-flight analysis, the distance of the center of mass to the landing slope was calculated by subtracting the vertical displacement of the landing slope from the corresponding center of mass of the skier-ski system. The contour of the landing hill was measured through the analysis of the lower leg segment of a skier skiing the landing slope. The value used was the ankle of the skier, so that the vertical displacement value used for the landing slope was actually approximately 10 cm above the surface of the snow. The vertical displacement of the center of mass for the preparation for landing analysis was calculated by subtracting the absolute value of the displacement of the center of mass for twelve and six frames prior to landing, from the vertical displacement of the ankle joint at the frame defined as heel contact of landing. As in the mid-flight analysis, the displacement of the landing slope was actually about 10 cm above the snow surface. Only the jumpers who exceeded 70 meters in distance could be compared in terms of the vertical displacement

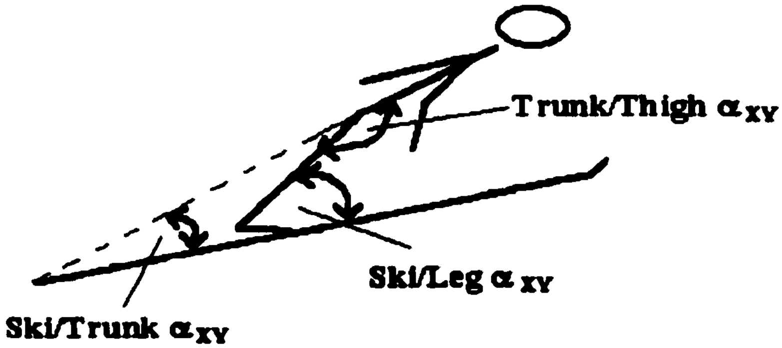


Figure 3a. Skier-Ski System Variables in the XY Plane.

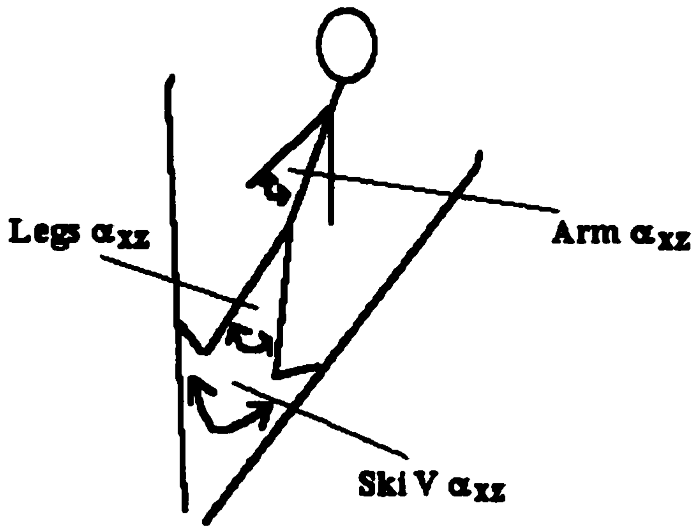
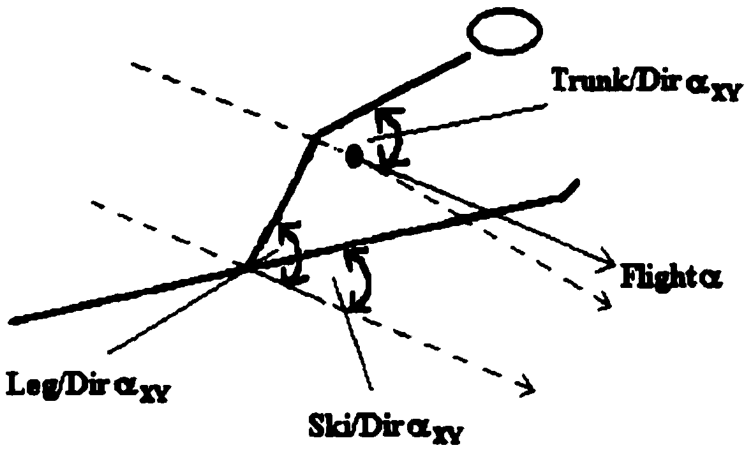
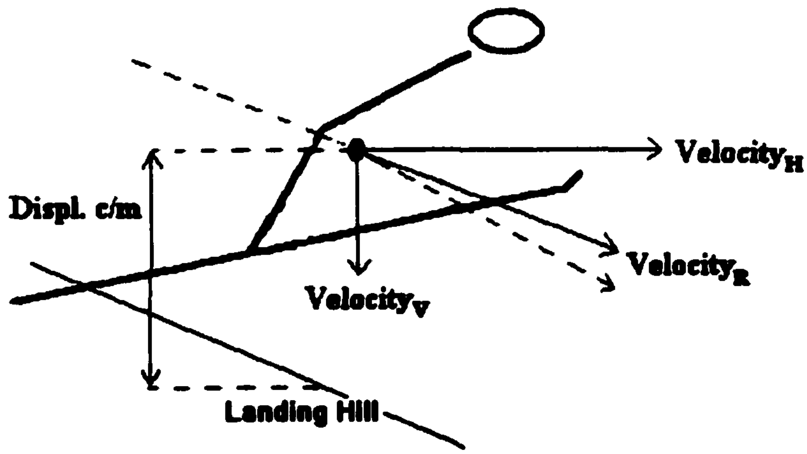


Figure 3b. Skier-Ski System Variables in the XZ Plane.



Flight α - The Angle of the Flight Curve

Figure 4. Skier-Ski System and Direction of Flight in the XY Plane.



Velocity$_H$ - Horizontal Velocity of the center of mass
Velocity$_V$ - Vertical velocity of the center of mass
Velocity$_R$ - Resultant velocity of the center of mass
Displ. c/m - Distance of the center of mass to the landing

Figure 5. Velocity and Flight Direction.

of the center of mass from the landing hill for the preparation for landing analysis. The reason for this is that the landing slope is a constant pitch between 70 and 88 meters. Thus, jumpers landing before the 70 meter mark are each landing on a slightly different angle of slope. Therefore the height of the center of mass before landing could not be standardized between subjects. Figure 5 presents the variables included in the velocity and flight direction subgroup.

Statistical Procedures

The statistical methods to be used in this study relate to:

1. Descriptive statistics.
2. The relationship between specific kinematic parameters and the distance jumped.
3. Regression analysis performed to predict distance jumped.
4. The structure of relationships among selected variables.

Descriptive Statistics

Means, standard deviations, minimum and maximum values for all measured variables were generated for both the mid-flight and the preparation for landing phase, to enhance the description of the variables.

Relationship 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 selected variables and the distance jumped. Correlation coefficients were calculated by employing subroutines from the Statistical Package for the Social Science (SPSS) package. Correlations meeting the .05 level of significance were reported, however only moderate to strong correlations were selected for further analysis and discussion.

Regression Analysis

Both multiple linear regression and stepwise regression analyses were used to determine the predictability of the dependent variable, distance jumped, for both the mid-

flight phase and the preparation for landing phase. The regression analysis gave further insight into the variables determined to be significant predictors of the criterion variable.

<u>The structure of relationships among selected variables</u>

A principal component, varimax rotated factor analysis was performed between selected variables for the analyzed phases of flight and the distance jumped. The factor analysis enabled us to generate a general view of the structure of intercorrelations among the observed variables for each of the analyzed phases (55 meters for the mid-flight phase and 12 frames prior to landing for the preparation for landing phase). The sign of the factor loadings (+,-) was critical to the interpretation and described the tendency of the relationship between the length of jump and the other variables. Variables with a significant relationship to the criterion (length of jump) were identified and the interpretation of the tendencies of measured variables were presented relative to the distance jumped.

Chapter 4

Results

This investigation was focused on examining the variables found in both the mid-flight phase, between 50m and 60m, and the preparation for landing phase. Variables selected for both of these phases were analyzed in order to determine their contribution to the distance jumped. The analysis will be described in three different sections for each of the two subsections of flight: a) quantification of the variables and their relationship to the dependent variable, distance jumped, b) prediction of the dependent variable through regression analysis and, c) structure of relationships among selected variables. The variables for mid-flight were analyzed at three different points during the flight path (50 meters, 55 meters and 60 meters) for each jumper. The second part of the analysis involved variables measured 12 frames (0.204 seconds) and 6 frames (0.102 seconds) prior to landing.

Mid-flight

Quantification of the Variables and the Relationship to Distance Jumped

Means, standard deviations, minimum and maximum values for all the variables were calculated to enhance the description and provide quantification for the variables thought to be associated with effective ski jumping flight. The mid-flight descriptive analysis focused on a subset of the top 25 jumpers on the basis of distance jumped. This group was selected for the mid-flight analysis since each of the top 25 jumpers were determined to be executing mid-flight characteristics through the analyzed field width. Jumpers with shorter distances may have actually have been in the late stages of flight or preparing to land and were omitted for this reason. Variables calculated at 55 meters will be discussed in order to provide the best representation of the mid-flight phase. The raw data results are presented in Appendix A1 for the mid-flight analysis (n=40) and Appendix A2 for the mid-flight analysis (n=25).

A correlation analysis for six independent variables and the distance jumped was conducted on the subset of 25 jumpers, each jumping over 69 meters. Significant correlations which are moderate to strong have been selected for further discussion and analysis. Significant product moment correlations between selected variables and the distance jumped are presented in Table 2 and are described below.

Distance. The mean distance jumped by the top 25 competitors was 73.14 meters. The standard deviation (SD) was 2.76. The minimum distance jumped included in this group was 69.0 meters, with the longest jump equal to 78.5 meters. The distance jumped during competitive events is unique to each particular hill and the prevailing external conditions, i.e. wind and snow. For this reason, it is of little value to compare between hills and events.

Displ. C/M. The value of the mean vertical displacement of the c/m was 1.66 meters (SD = .23). The minimum and maximum scores were 1.19 meters and 2.23 meters. The value of the vertical displacement of the center of mass was calculated from the landing hill and gives an indication of the height of the flight curve at 55 meters. The vertical displacement of the center of mass correlated strongly in the positive direction with the distance jumped ($r = .7484$ $p<.05$, 2-tailed). This relationship suggests that the best jumpers had a higher vertical displacement of the center of mass at 55 meters.

<u>Trunk/Dir α_{XY}</u>. The mean value of the trunk and direction of flight angle was 51.07 degrees (SD = 4.63). The minimum and maximum were both 41.52 degrees and 62.43 degrees respectively. The angle of the trunk relative to the direction of flight is a measure of the skiers forward lean and is frequently referred to as the angle of attack in the literature (Jin et al., 1995). The trunk angle relative to the direction of flight formed a moderate negative correlation with the dependent variable, distance jumped (r = -.5728, p<.05 2-tailed). A small angle between the trunk and direction of flight appears to be associated with a greater distance jumped.

<u>Ski/Trunk α_{XY}</u>. The mean angle of the ski and trunk angle at 55 meters was 16.22 degrees (SD = 6.48). Minimum and maximum angle values were 4.99 degrees and 26.19 degrees respectively. The ski and trunk angle also formed a moderate negative correlation with the dependent variable, distance jumped (r = -.5626 p< .05, 2-tailed). Decreasing the angle formed by extending the lines from the trunk and ski segments also appears to be associated with the distance jumped.

<u>Ski/Leg α_{XY}</u>. The mean angle between the ski and leg segments at 55 meters was 26.44 degrees (SD = 7.31). The minimum and maximum values were 13.82 degrees and 44.95 degrees. The ski and leg angle formed a moderate negative correlation with the dependent variable, distance jumped (r = -. 5070 p<.05, 2-tailed). This relationship suggests the importance of a small ski and leg angle during mid-flight in order to increase the distance jumped.

Seven variables were significantly correlated to the dependent variable, distance jumped. Of these, only the variables Displ. c/m, Trunk/Dir α_{XY}, Ski/Trunk α_{XY} and

Ski/Leg α_{XY} showed moderate to strong relationships and warrant further explanation in the discussion section (chapter 5). Three variables: Leg/Dir α_{XY}, Flight α, and Velocity$_{IR}$ were significantly but weakly related to the dependent variable. Refer to Table 2 for specific correlation values.

Table 2 - Mid-flight

Correlation between selected independent variables (55 meters)

and dependent variable, distance jumped (n = 25)

Correlation:	Distance	Velocity$_{IR}$	Flight α	Leg/Dir α_{XY}	Ski/Dir α_{XY}	Trunk/ Dir α_{XY}	Ski/Leg α_{XY}	Ski/Trunk α_{XY}	Trunk/ Thigh α_{XY}
Distance	1.0000								
Velocity$_{IR}$	.4410*	1.0000							
Flight α	-.4479*	-.4429*	1.0000						
Leg/Dir α_{XY}	-.4632*	.0472	.0102	1.0000					
Ski/Dir α_{XY}	.1948	-.1373	-.2008	.4264*	1.0000				
Trunk/Dir α_{XY}	-.5728*	-.2577	.3620	.4400*	.1264	1.0000			
Ski/Leg α_{XY}	-.5070*	.2423	.1943	.7052*	-.2103	.2184	1.0000		
Ski/Trunk α_{XY}	-.5626*	-.0696	.4085*	-.0201	-.6944*	.6251*	.3124	1.0000	
Trunk/Thigh α_{XY}	.1852	-.0661	.2788	-.6508*	-.1807	.1531	-.3765	.2503	1.0000
Ski V α_{XZ}	.2695	.3584	-.1859	.2797	.1214	-.3258	.2754	-.3303	-.4406*
Arm α_{XZ}	-.3397	.0490	2390	.4334*	-.1633	.2335	.5007*	.2995	-.3360
Legs α_{XZ}	.1164	.0543	-.1862	.2182	.0867	-.2045	.2018	-.2184	-.3882*
Displ. C/M	.7484*	.1530	-.2292	-.3285	.1501	-.1888	-.4006*	-.2559	.2177
Velocity$_H$	.1694	.3192	-.4327*	-.0210	-.0661	-.5301*	.0279	-.3237	-.3579
Velocity$_V$	.1316	-.0264	-.2364	.0117	.2121	.3157	-.1679	.0610	.1953
Velocity$_R$	.0766	.2412	-.2135	-.0491	-.1624	-.4752*	.0741	-.2113	-.2925
ΔVelocity$_H$	.2138	.4104*	.0344	-.1770	-.3938*	-.2123	.2132	.1539	.1510

2-tailed Signif: * - .05

Table 2 - Mid-flight

(continued)

Correlation:	Ski V α_{XZ}	Arm α_{XZ}	Legs α_{XZ}	Displ. C/M	$Velocity_H$	$Velocity_V$	$Velocity_R$	$\Delta Velocity_H$
Distance								
$Velocity_{IR}$								
Flight α								
Leg/Dir α_{XY}								
Ski/Dir α_{XY}								
Trunk/Dir α_{XY}								
Ski/Leg α_{XY}								
Ski/Trunk α_{XY}								
Trunk/Thigh α_{XY}								
Ski V α_{XZ}	1.0000							
Arm α_{XZ}	.0983	1.0000						
Legs α_{XZ}	.2944	.0426	1.0000					
Displ. C/M	.1136	-.2673	.1205	1.0000				
$Velocity_H$	.2942	.2464	-.2530	-.1834	1.0000			
$Velocity_V$	-.1856	-.4404*	.4028*	.3606	.7735*	1.0000		
$Velocity_R$	.2431	.3207	-.3398	-.2495	.9695*	-.8950*	1.0000	
$\Delta Velocity_H$	-.1158	.3088	-.2111	.2099	.1767	-.2123	.2062	1.0000

2-tailed Signif: * - .05

Relationships Among the Selected Variables

A number of the independent variables included in the correlational analysis formed relationships significant at the .05 level of significance and are discussed below.

1. Strong correlations were found between the components of velocity. Vertical velocity ($Velocity_V$) and horizontal velocity ($Velocity_H$) were correlated ($r = .7735$ $p<.05$, 2-tailed), while vertical velocity ($Velocity_V$) and resultant velocities ($Velocity_R$) were related at $r = -.8950$ $p<.05$, 2-tailed. The horizontal and resultant components were also positively related ($r = .9695$ $p<.05$, 2-tailed). The strong correlations are based on the mathematical relationships of these variables.

2. The angle of the ski and leg (Ski/Leg α_{XY}) correlated strongly and positively with the angle formed between the leg and direction of flight (Leg/Dir α_{XY}), ($r = .7052$ $p<.05$, 2-tailed). This relationship shows that the two variables partially measure the same characteristic of forward lean.

3. The ski and trunk angle (Ski/Trunk α_{XY}) correlated moderately and positively with the corresponding angle formed between the trunk and angle of the flight curve (Trunk/Dir α_{XY}), ($r = .6251$ $p<.05$, 2-tailed). Similarly, the ski and trunk angle (Ski/Trunk α_{XY}) correlated negatively with the corresponding angle between the ski and angle of the flight curve (Ski/Dir α_{XY}), ($r = -.6944$ $p<.05$, 2-tailed).

4. The angle between the leg segment and the direction of flight (Leg/Dir α_{XY}), formed a moderate negative correlation with the trunk and thigh angle (Trunk/Thigh α_{XY}), ($r = -.6508$ $p<.05$, 2-tailed).

The following correlations were weakly but significantly related: (Refer to Table 2 for specific values).

- right arm and trunk angle(Arm α_{XZ}) and the leg and direction of flight angle (Leg/Dirα_{XY}).
- right arm (Arm α_{XZ}) and the ski and leg angle (Ski/Leg α_{XY}).
- inrun velocity (Velocity$_{IR}$) and the angle of the flight curve (Flight α).
- inrun velocity (Velocity$_{IR}$) and the change in horizontal velocity (ΔVelocity$_{H}$).
- ski and direction (Ski/Dir α_{XY}) and the change in horizontal velocity (ΔVelocity$_{H}$).
- horizontal velocity (Velocity$_{H}$) and the angle of the flight curve (Flight α).
- vertical velocity (Velocity$_{V}$) and the arm angle (arm α_{XZ}).
- vertical velocity (Velocity$_{V}$) and the angle between the legs (legs α_{XZ}).
- trunk and the direction (Trunk/Dir α_{XY}) and the leg and the direction of flight (Leg/Dir α_{XY}).
- leg and direction (Leg/Dir α_{XY}) and the ski and the direction of flight (Ski/Dir α_{XY}).
- ski and trunk angle (Ski/Trunk α_{XY}) and the angle of the flight curve (Flight α).
- ski angle (Ski V α_{XZ}) and the trunk and thigh angle (Trunk/Thigh α_{XY}).
- angle between the legs (Legs α_{XZ}) and the trunk and thigh angle (Trunk/Thigh α_{XY}).
- vertical displacement of the center of mass (Displ. c/m) and the ski and leg angle (Ski/Leg α_{XY}).

Mid-flight

Multiple Regression Analyses

A multiple regression analysis was conducted on the set of data at the 55 meter mark from the top 25 jumpers whose distance was greater than or equal to 69 meters. Following the correlation analysis, it was noted that a number of variables that were part of the skier-ski system and direction of flight exhibited multi-colinearity. For this reason, Leg/Dir α_{XY}, Trunk/Dir α_{XY} and Ski/Dir α_{XY} were not included in the regression analysis.

Using the method of least squares, a multiple regression model was computed to predict the distance jumped. The results of this analysis are presented in Table 2. The prediction equation with the variables arranged in the order of their importance in predicting the distance jumped was:

$$Y' = 54.7574 - .2100X_1 + .6847X_2 + .2317X_3 - .1437X_4 + .1156X_5 + .0687X_6$$

where:

Y' = Dependent variable (Distance)

X_1 = Ski/Leg α_{XY}

X_2 = ΔVelocity$_H$

X_3 = Ski V α_{XZ}

X_4 = Ski/Trunk α_{XY}

X_5 = Trunk/Thigh α_{XY}

X_6 = Legs α_{XZ}

The multiple correlation coefficient, an indication of the amount of the population that is accounted for by the model, was .7518. The F-test statistic, a measure of how good the model is, was 9.089, with the significance of F = .0001, $p<.001$. The hypothesis that there is no order to the relative importance of each of the selected independent variables in predicting the distance jumped, was rejected at the .001 level of significance.

Table 3

Regression Analysis to Predict Distance Jumped

From Selected Variables at 55 meters

Variable	B	SE B	Beta	T	Sig T
Ski/Leg α_{XY}	-.209992	.059454	-.555674	-3.532	.0024
ΔVelocity$_H$	.684665	.198327	.440304	3.452	.0028
Ski V α_{XZ}	.231654	.080174	.411015	2.889	.0098
Ski/Trunk α_{XY}	-.143707	.062925	-.337043	-2.284	.0347
Trunk/Thigh α_{XY}	.115552	.065405	.263922	1.767	.0942
Legs α_{XZ}	.068694	.039828	.229280	1.725	.1017
(Constant)	54.757355	11.715314		4.674	.0002

The six 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 are presented in Table 4. The stepwise equation for predicting the distance jumped was:

$$Y' = 75.5741 - .1334X_1 - .2298X_2 + .6781X_3 + .2165X_4$$

where:

Y' = Dependent variable (Distance)

X_1 = Ski/Trunk α_{XY}

X_2 = Ski/Leg α_{XY}

$X_3 = \Delta Velocity_H$

$X_4 = Ski\ V\ \alpha_{XZ}$

The variables in the equation appear in order of selection for the stepwise analysis. The multiple correlation coefficient for the model was .6811. This indicated that the model which included only four of the original six variables was only slightly less useful in predicting distance jumped as the full model.

It is important to note that the variable ski and trunk angle was selected first to enter the stepwise analysis, in spite of being only fourth in order of significance, from the full regression analysis. This may be explained by the ability of stepwise analyses to take into account variability that may be "shared" among the various predictor variables.

Table 4

Stepwise Regression to Predict Distance Jumped

from Selected Variables at 55 meters

Variable	B	SE B	Beta	T	Sig T
Ski/Trunk α_{XY}	-.133440	.063680	-.312964	-2.095	.0491
Ski/Leg α_{XY}	-.229765	.056900	-.607995	-4.038	.0006
ΔVelocity$_H$	.678110	.204546	.436088	3.315	.0035
Ski V α_{XZ}	.216482	.084280	.384096	2.569	.0183
(Constant)	75.574139	2.135909		35.383	.0000

Mid-flight

Structure of Relationships Among Selected Variables

A factorial analysis was performed for the variables of the mid-flight in order to explore factors that represented relationships among the many interrelated variables. The set of data from the entire sample (n = 40) was used for this analysis because factor analysis seeks to simplify the data through the intercorrelations, and is not a prediction method. The factor extraction method used was principal component analysis, followed by varimax rotation, which attempts to minimize the number of variables that have high loadings on a factor. The mid-flight variables from 55m were included in the factor analysis. Three factors were extracted from the 13 variables, to explain 75.2% of the variance. Table 5 presents the eigenvalues and the percentage of variance predicted by each of the extracted factors. The factor loadings and communalities are presented in Table 6. Communality values for the variables were all over .5, except for the angle of the skis (XZ plane).

Table 5

Final Factor Statistics -Mid-flight (55 meters)

Factor	Eigenvalue	% Of Variance	Cumulative %
1	5.08949	39.1	39.1
2	3.15672	24.3	63.4
3	1.53534	11.8	75.2

Each of the positive factor loadings is interpreted as being maximized in the sample of jumpers in mid-flight, while the tendency of the negative factors is to be minimized.

Table 6

Rotated Factor Matrix - Mid-flight (55 meters)

	Factor			
Variable	**1**	**2**	**3**	**Communality**
Distance	***.68349***	-.05397	***-.58948***	.81756
Flight α	***-.64391***	.14731	.39495	.59231
Ski/Trunk α_{XY}	***-.80098***	.22274	.28220	.77082
Displ. C/M	***.65892***	.19055	-.57687	.80327
Ski V α_{XZ}	***.69074***	.01337	.02030	.47771
Ski/Dir α_{XY}	***.85785***	.26896	-.02755	.80900
Trunk/Dir α_{XY}	-.02536	***.69463***	.38532	.63162
Velocity_H	.17787	***-.94596***	.02311	.92702
Velocity_R	-.01140	***-.95789***	.13055	.93473
Velocity_V	.30276	***.81098***	-.31619	.84933
Leg/Dir α_{XY}	.02419	.11287	***.96947***	.95320
Ski/Leg α_{XY}	-.18032	-.06551	***.68186***	.50174
Trunk/Thigh α_{XY}	.37132	.22887	***-.72319***	.71327

*** bold type indicates the variables which load strongly for each factor.**

Positive factor loadings for factor 1 included the variables distance jumped, ski and direction of flight angle, ski angle (XZ plane) and vertical displacement. The negative factor loadings for factor 1 were flight angle and the ski and trunk angle. The loadings for

factor 2 included all three inter-related velocity variables and the angle between the trunk and direction of flight. The horizontal and resultant velocities were very strong negative loadings, while the vertical velocity and trunk and direction variables were positive factor loadings. The third factor included positive loadings of the leg and direction of flight and the ski and leg angle, and a negative loading for the trunk and thigh angle. Factor three also contained a fairly high negative loading for the distance jumped variable (-.59848). As maximizing the distance jumped is the goal of ski jumping technique, the other factors are discussed relative to the factor loading for distance jumped. In this sense, distance jumped becomes the criterion variable in the interpretation of the factor analysis, although factor analysis is not a prediction method.

Preparation for Landing Analysis

Quantification of the Variables and the Relationship to Distance Jumped

Means, standard deviations, minimum and maximum values for all the variables were calculated to enhance the description and provide quantification for the variables thought to be associated with an effective preparation for landing. The variables were measured at 12 frames (0.204 sec.) prior to landing. The preparation for landing descriptive analysis for all variables, except the vertical displacement of the center of mass, includes data for the entire sample of jumpers. It is relevant to study the entire sample since each subject was measured relative to heel contact during landing. The results are presented in Appendix B1 for the preparation for landing analysis (n=40).

The variable vertical distance of the center of mass from the landing hill was analyzed for a subset of the subjects who obtained distances further than 70 meters. The slope of the landing hill is constant between the points of 70 and 88 meters, however jumps ending before or after these points are not directly comparable in terms of the height of the center of mass above the landing slope. The descriptive results are presented in Table B2 for the jumpers landing past 70 meters (n=21).

It was believed that the angle of the knee played an important role in the positioning of the skier-ski system during the preparation for landing phase. For this reason, the right knee angle, the ski and leg angle, the ski and trunk angle and the trunk and thigh angle were all measured and analyzed six frames prior to landing.

A correlation analysis was performed on all 40 analyzed jumpers for all variables, except the vertical displacement of the center of mass. Significant correlations which are moderate to strong have been selected for further discussion and analysis. The product moment correlations between selected variables and the distance jumped are presented in Table 7.

A second correlation analysis was completed for the subset of 21 jumpers who achieved a distance of 70 meters or greater for all variables including the vertical displacement of the center of mass. Variables displaying moderate to strong correlations have been selected for further discussion and analysis. Results of the correlation are presented in Table 8.

A third correlation analysis was conducted on the entire sample of 40 jumpers and measured the skier-ski variables 6 frames prior to landing (.102 seconds). Moderate to strong correlations are discussed further in Chapter 5. Results of the statistical analysis are presented in Table 9.

A description of the results for two independent variables selected from the first correlation analysis (n = 40, measured 12 frames before landing) with the dependent variable, distance jumped are presented below.

Distance jumped. The mean distance jumped by the 40 competitors was 69.75 meters. The standard deviation (SD) was 4.61. The minimum distance jumped included in this group was 60.5 meters, with the longest jump equal to 78.5 meters. It is of importance to the preparation for landing analysis to note that none of the jumps surpassed the critical point of the hill (90 meters). Significant correlations between independent variables and the distance jumped included the vertical velocity of the center of mass, the flight angle, the ski and trunk angle and the trunk and thigh angle.

Velocity$_Y$. The mean value of the vertical velocity variable was -17.62 meters per second (SD=.72). The minimum and maximum values were -16.200 and -19.135. The vertical velocity indicates how quickly the jumper is moving downward towards the landing slope. Therefore, minimizing this value indicates a slower downward flight to the hill. The independent variable vertical velocity formed a strong negative correlation with the dependent variable, distance jumped ($r = -.8037$ $p<.05$, 2-tailed). The negative increase in vertical velocity suggests that the jumpers achieving the greatest distance are actually coming down to the landing more quickly than the subjects with shorter jumps.

Flight α. The direction of flight for the entire sample of 40 athletes 12 frames prior to landing was 39.17 degrees (SD = .92). The minimum was 37.332 degrees, while the maximum angle was 40.713 degrees. A smaller angle of flight indicated a more forward flight direction and was pointed away from the hill, compared to a larger flight angle. The flight angle, correlated positively with the dependent variable, distance jumped ($r = .6318$, $p<.05$, 2-tailed). This result indicates a moderate association between greater distance jumped and a greater angle between the flight curve and the horizontal axis. Interestingly, the jumpers achieving the greatest distance are generally dropping into the hill more sharply than the jumpers landing earlier.

The independent variables ski and trunk angle (Ski/Trunk α_{XY}) and the trunk and thigh angle (Trunk/Thigh α_{XY}) also correlated significantly with the dependent variable distance jumped. However, these two correlations were weak and were not chosen for further discussion. Refer to Table 7 for specific values.

Table 7 - Preparation for Landing

Correlation between selected independent variables (.204 seconds prior to landing) and dependent variable, distance jumped (n = 40)

Correlation:	Distance	Flight α	Trunk /Thigh α_{XY}	Ski/Trunk α_{XY}	Ski/Leg α_{XY}	Knee α_{XY}
Distance	1.0000					
Flight α	.6318*	1.0000				
Trunk/Thigh α_{XY}	.4245*	.1204	1.0000			
Ski/Trunk α_{XY}	.4845*	.1837	.5458*	1.0000		
Ski/Leg α_{XY}	.0386	.1461	-.2024	.2450	1.0000	
Knee α_{XY}	.2084	.1258	.7026*	.1426	.3104	1.0000
Arm α_{XZ}	-.2141	-.1149	-.1435	-.4203*	-.2167	-.0370
Skis α_{XZ}	.0224	.0021	.1752	.1450	.1903	.2540
Legs $\alpha_{X\dot{Z}}$	-.0603	-.0838	-.1456	.1273	.6190*	.1844
$Velocity_V$	-.8037*	.5429*	-.4039*	-.3738*	.1073	-.1552
$\Delta Velocity_H$	-.1419	.3393*	-.4449*	-.1980	.3316*	-.1665

2-tailed Significance: * - .05

Table 7 - Preparation for Landing

(continued)

Correlation:	Arm α_{XZ}	Skis α_{XZ}	Legs α_{XZ}	Velocity$_V$	ΔVelocity$_H$
Distance					
Flight α					
Trunk/Thigh α_{XY}					
Ski/Trunk α_{XY}					
Ski/Leg α_{XY}					
Knee α_{XY}					
Arm α_{XZ}	1.0000				
Skis α_{XZ}	-.1532	1.0000			
Legs α_{XZ}	-.1368	.2631	1.0000		
Velocity$_V$	.0955	.0167	.0764	1.0000	
ΔVelocity$_H$	.0275	.0647	.2067	.2695	1.0000

2-tailed Significance: * - .05

<u>Significant Correlations Between Variables</u>

Several of the independent variables of the entire sample (n = 40) formed significant relationships at 12 frames prior to landing which may be important to note in the preparation for landing analysis.

1. A strong positive correlation existed between the trunk and thigh angle (Trunk/Thigh α_{XY}) and the knee bend angle (Knee α_{XY}), (r = .7026 p<.05, 2-tailed). The collinear relationship illustrates the strong tendency for the jumper to bend at the hips as the knees are bent.

2. The ski and leg angle (Ski/Leg α_{XY}) was moderately associated with the angle between the legs in the frontal plane (Legs α_{XZ})(r = .6190 p<.05, 2-tailed). This relationship suggests that the legs tend to spread out as the angle opens up between the ski and leg.

3. The ski and trunk angle (Ski/Trunk α_{XY})was moderately correlated with the angle of the trunk and thigh angle (Trunk/Thigh α_{XY}) (r = .5458 p<.05, 2-tailed). The presence of a linear relationship between these variables shows that they do, at least partially, measure the same trait. Therefore, an increase in either variable is normally accompanied by an increase in the other.

4. The vertical velocity (Velocity$_V$) and the angle of the flight curve (Flight α) showed a moderate positive relationship (r = .5429 p<.05, 2-tailed). This finding suggests that as the vertical velocity becomes greater in the negative direction, the angle of the flight curve slopes downward correspondingly.

The following correlations were weakly but significantly correlated:

- **change in horizontal velocity ($\Delta Velocity_H$) and the trunk and thigh angle (Trunk/Thigh α_{XY}).**
- **ski and trunk angle (Ski/Trunk α_{XY}) and the right arm and trunk angle (Arm α_{XZ}).**
- **vertical velocity ($Velocity_V$) and trunk and thigh angle (Trunk/Thigh α_{XY}).**
- **vertical velocity ($Velocity_V$) and the ski and trunk angle (Ski/Trunk α_{XY}).**
- **angle of the flight curve (Flight α) and the change in horizontal velocity ($\Delta Velocity_H$).**
- **the ski and leg angle (Ski/Leg α_{XY}) and the change in horizontal velocity ($\Delta Velocity_H$).**

The second correlation analysis performed involved the 21 subjects who jumped to the 70 meter mark and beyond. This subset was analyzed to explore relationships with the vertical displacement of the center of mass variable. This variable could only be investigated for jumpers going past 70 meters, as the slope of the landing is constant between 70 and 88 meters. The statistical routine performed was a correlation analysis of all 11 independent variables, to determine which variables were significantly correlated to the vertical displacement of the C/M. Three variables were found to meet a significance level of $p<.05$ or less with the Displ. C/M. The moderate correlation of the vertical velocity was selected for further discussion and analysis. The significant product moment correlations between selected variables and the vertical displacement are presented in Table 8.

Displ. C/M. From the subset of jumpers (n=21) achieving a jump past the normal point (70 meters), the mean of vertical displacement was 4.13 meters (SD=.13). The minimum displacement was 3.924 and the maximum was 4.310. The value of vertical displacement is indicative of the height of the calculated center of mass above the center of the ankle joint at landing. Distance jumped (Distance), vertical velocity ($Velocity_V$) and the ski and trunk angle (Ski/Trunk α_{XY}) formed significant correlations with the Displ. C/M variable.

1. The vertical velocity (Velocity$_V$) was moderately related to the displacement of the center of mass (Displ. C/M) for the subset of n=21 jumpers who jumped 70 meters or greater ($r = -.6515$ $p<.05$, 2-tailed). The interpretation of the relationship is that the jumpers with a greater height above the landing hill 12 frames prior to landing also generally have an associated negative increase in vertical velocity.

The following correlations were weak but significant at the .05 level.

- vertical displacement of the center of mass (Displ. C/M) and the ski and trunk angle (Ski/Trunk α_{XY}).
- distance jumped (Distance) and the vertical displacement of the center of mass (Displ. C/M).

Table 8

Correlation between selected independent variables

and dependent variable, distance jumped (n = 21)

12 frames prior to landing

Correlation:	Distance	Flight α	Trunk/ Thigh α_{XY}	Ski/ Trunk α_{XY}	Ski/Leg α_{XY}	Knee α_{XY}
Distance	1.0000					
Flight α	.2310	1.0000				
Trunk/Thigh α_{XY}	.3370	-.0393	1.0000			
Ski/Trunk α_{XY}	.3617	-.1046	.5160*	1.0000		
Ski/Leg α_{XY}	-.0155	.1555	-.2844	.1744	1.0000	
Knee α_{XY}	.0608	.1892	.4264	-.0969	.4684*	1.0000
Arm α_{XZ}	-.4255	-.1424	.1367	-.3188	-.0313	.3929
Skis α_{XZ}	.2036	-.0151	.2554	.1892	.2770	.3876
Legs α_{XZ}	.0402	-.1660	-.1483	.2045	.4968*	.1256
$Velocity_V$	-.6368*	-.1409	-.1961	-.2894	.1928	.2030
$\Delta Velocity_H$	-.3536	.4529*	-.4312	-.3609	.2212	.0245
Displ. C/M	.4547*	.1255	.1679	.4570*	.0143	-.1819

2-tailed Signif: * - .05

Table 8

(continued)

Correlation:	Arm α_{XZ}	Skis α_{XZ}	Legs α_{XZ}	$Velocity_V$	$\Delta Velocity_H$	Displ. C/M
Distance						
Flight α						
Trunk/Thigh α_{XY}						
Ski/Trunk α_{XY}						
Ski/Leg α_{XY}						
Knee α_{XY}						
Arm α_{XZ}	1.0000					
Skis α_{XZ}	-.1746	1.0000				
Legs α_{XZ}	-.1129	.3676	1.0000			
$Velocity_V$	.3108	.1908	.0354	1.0000		
$\Delta Velocity_H$	.1792	.0929	.0292	.3991	1.0000	
Displ. C/M	-.3489	-.3571	-.0835	-.6515*	-.4095	1.0000

2-tailed Signif: * - .05

The third correlation analysis performed on the preparation for landing phase data included variables of the skier-ski system at six frames prior to landing. The entire sample of 40 athletes were included in the analysis in order to determine the strength of relationships between variables in the final preparation for landing phase. Variables showing a moderate to strong relationship are discussed later in Chapter 5. Six significant relationships were formed and are presented in Table 9.

1. The trunk and thigh angle (Trunk/Thigh α_{XY}) formed a strong, positive linear relationship with the ski and trunk angle (Ski/Leg α_{XY}), ($r = .7576$ $p<.05$, 2-tailed). The correlation is similar to that found in the analysis performed at 12 frames prior to landing.

2. The angle of the right knee (Knee α_{XY}) was moderately correlated with the trunk and thigh angle (Trunk/Thigh α_{XY}) six frames prior to landing for the 40 subjects ($r = .6103$ $p<.05$, 2-tailed). As the knee is bending coming into the landing, the trunk and thigh angle opens correspondingly.

3. The angle of the right knee (Knee α_{XY}) was moderately correlated to the angle of the ski and leg segments (Ski/Leg α_{XY}) at 6 frames prior to landing ($r = .5660$ $p<.05$, 2-tailed). The increased bend in the knee was associated with an opening of the ski and leg angle at 6 frames back, but not at the earlier point of 12 frames back from landing.

The following correlations were weakly but significantly related:

- right knee angle (Knee α_{XY}) and angle of the ski and trunk (Ski/Trunk α_{XY}).
- ski and trunk angle (Ski/Trunk α_{XY}) and distance jumped (Distance).
- trunk and thigh angle (Trunk/Thigh α_{XY}) and distance jumped (Distance).

Table 9

Correlation between selected independent variables

and dependent variable, distance jumped (n = 40)

6 frames prior to landing

Correlation:	Distance	Knee α_{XY}	Ski/ Leg α_{XY}	Ski/Trunk α_{XY}	Trunk/ Thigh α_{XY}
Distance	1.0000				
Knee α_{XY}	.2328	1.0000			
Ski/Leg α_{XY}	.2090	.5660*	1.0000		
Ski/Trunk α_{XY}	.4640*	.3986*	.2697	1.0000	
Trunk/Thigh α_{XY}	.3297*	.6103*	-.0881	.7576*	1.0000

2-tailed Significance: * - .05

Preparation For Landing

Multiple Regression Analyses

The results of the correlation analysis led the principal investigator to include six variables from the sample of 40 subjects, measured at 12 frames prior to landing, in the multiple regression analysis. For the reason of multi-colinearity, the variable right knee bend angle was excluded from the regression.

Using the method of least squares, a multiple regression model was computed to predict the distance jumped. The results of this analysis are presented in Table 10. The prediction equation with the variables arranged in the order of their importance in predicting the distance jumped was:

$$Y' = 54.6983 - 3.6103X_1 + 1.4070X_2 + .0857X_3 + .0243X_4 - .0076X_5 + .0131X_6$$

where:

Y' = Dependent variable (distance jumped)

X_1 = Velocity$_V$

X_2 = Flight α

X_3 = Ski/Trunk α_{XY}

X_4 = Trunk/Thigh α_{XY}

X_5 = Arm α_{XZ}

X_6 = Ski/Leg α_{XY}

The multiple correlation coefficient, an indication of the amount of the population that is accounted for by the model, was .7471. The F-test statistic, a measure of how good the model is, was 16.2452, with the significance of F = .0001, p<.001. The hypothesis that there is no order to the relative importance of each of the selected independent variables in predicting the distance jumped, was rejected at the .001 level of significance.

Table 10

Regression Analysis to Predict Distance Jumped

From Selected Preparation For Landing Variables

(12 frames prior to landing)

Variable	B	SE B	Beta	T	Sig T
Velocity$_V$	-3.601323	.765683	-.559453	-4.703	.0000
Flight α	1.406980	.543006	.281004	2.591	.0141
Ski/Trunk α_{XY}	.085653	.069581	.157081	1.231	.2270
Trunk/Thigh α_{XY}	.024325	.036801	.077390	.661	.5132
Arm α_{XZ}	-.007645	.016267	-.045951	-.470	.6415
Ski/Leg α_{XY}	.013139	.054646	.024803	.240	.8115
(Constant)	54.698285	17.617978		-3.105	.0039

The six 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 are presented in Table 11. The stepwise equation for predicting the distance jumped was:

$$Y' = -54.0320 - 3.6512X_1 + 1.4180X_2 + .1207X_3$$

where:

Y' = Dependent variable (Distance)

X_1 = Velocity_V

X_2 = Flight α

X_3 = Ski/Trunk α_{XY}

The variables in the equation appear in order of selection for the stepwise analysis. The multiple correlation coefficient for the model was .7423. This indicated that the model which included only three of the original six variables was no less useful in predicting distance jumped as the full model.

Table 11

Stepwise Regression to Predict Distance Jumped from Selected Preparation for Landing Variables (12 frames prior to landing)

Variable	B	SE B	Beta	T	Sig T
Velocity_V	-3.651206	.687550	-.567203	-5.310	.0000
Flight α	1.417996	.504615	.283204	2.810	.0080
Ski/Trunk α_{XY}	.120730	.049758	.221409	2.426	.0204
(Constant)	-54.031968	16.725420		-3.231	.0026

Preparation For Landing

<u>Structure of Relationships Among Selected Variables</u>

A principle component (varimax rotation) factor analysis was performed on variables thought to be critical in the performance of the preparation for landing phase. Variables known to be related to the distance jumped or correlated with variables that were related to the criterion variable were included, in order to provide insight into the complex movements. The variables entered were measured at 12 frames (.204 seconds) before heel contact of landing.

The analysis extracted three factors from the eight variables included in the analysis, to explain 74.7% of the variance. Communality values for the variables were all over .50, which is interpreted to mean that over 50 percent of the variance in each variable was accounted for by the three factors. Table 12 presents the eigenvalues and the percentage of variance predicted by each of the extracted factors. The factor loadings and communalities are presented in Table 13. The eight variables chosen to be entered into the factor analysis were all seen to be related in some way with the distance jumped. Two variables, leg and leg angle and the ski and leg angle were omitted with the knowledge that they had no relationship with the distance jumped and little or no relationship with other variables that were related to the criterion variable. Inclusion of relatively unrelated variables results in the creation of separate factors with strong loadings on only one variable and adds nothing to the interpretation of the factor analysis.

Table 12

Final Factor Statistics - Preparation for Landing

Factor	Eigenvalue	% Of Variance	Cumulative %
1	3.18432	39.8	39.8
2	1.64317	20.5	60.3
3	1.14506	14.3	74.7

The first factor, which accounted for 39.8 percent of the variance found within the sample, included strong loadings for distance, flight angle and vertical velocity. The positive loadings for distance and flight angle suggests that to maximize distance, the flight angle must be maximized. The vertical velocity was minimized based on the negative loading, which in other terms means that the velocity should be increasing in the negative direction in order to maximize distance jumped. The second factor included strong positive loadings for both the right knee and the trunk and thigh angle. These two inter-correlated variables should both be maximized during the preparation for landing phase, in order to maximize the distance jumped. Factor two also contained a moderately strong negative loading for the change in horizontal velocity variable. This illustrates that the change in horizontal velocity is actually negative, or decreases, in relation to the maximizing of the right knee angle and the trunk and thigh angle. The third and final factor accounts for the contribution of the right arm angle and the ski and trunk angle. The positive loading of the right arm indicated it's minimization in relation to the ski and trunk angle and also distance jumped. The ski and trunk angle is negatively factored, but in relation to the negative factor loading of the distance jumped, increases with greater distance jumped.

Table 13

Rotated Factor Matrix - Preparation for Landing

	Factor			
Variable	**1**	**2**	**3**	**Communality**
Distance	***.85018***	.22915	-.26997	.84820
Flight α	***.90334***	-.19502	.01651	.85433
Velocity$_V$	***-.79148***	-.28826	.15591	.73383
Knee α$_{XY}$	.20124	***.73860***	.16853	.61443
Trunk/Thigh α$_{XY}$	.27599	***.86470***	-.19992	.86385
Δ Velocity$_H$	.20197	***-.71130***	.19778	.58585
Ski/Trunk α$_{XY}$	.29947	.32490	***-.72650***	.72305
Arm α$_{XZ}$	-.04983	.07027	***.86116***	.74901

* bold type indicates the variables which load strongly for each factor.

Chapter 5

Discussion

The results of the mid-flight analysis will be discussed under the following headings: (a) relationship to the dependent variable, distance jumped, (b) prediction of the dependent variable and, (c) structure of intercorrelation relationship among selected variables.

Mid-flight

Relationship to the Dependent Variable

Seven variables were seen to be correlated to the dependent variable, distance jumped. They were: 1) inrun, 2) flight angle, 3) leg and direction of flight, 4) trunk and direction of flight, 5) ski and leg angle, 6) ski and trunk angle and, 7) vertical displacement. Of these relationships with the dependent variable, only the variables Displ. c/m, Trunk/Dir α_{XY}, Ski/Trunk α_{XY} and Ski/Leg α_{XY} showed moderate to strong correlations and will be examined further. Each of these variables will be discussed regarding their importance to the distance jumped as well as to the independent variables correlated with each.

Vertical displacement was strongly related to distance jumped, indicating that the jumpers flying the furthest were also flying the highest during the mid-flight phase. Jost (1994), in a study of the flight parameters on a 120 meter hill, noted that more successful jumpers flew higher and that the height of the flight curve at the point of observation was already a consequence of previous and measured kinematic parameters. The strong relationship between the height of the center of mass and the distance jumped was expected, since the jumpers who jump the furthest must also demonstrate the highest flight trajectories to get them further down the hill. In order for a jumper to maximize the distance jumped, they must not only increase the height of the flight curve, but optimize the movements that contribute to attaining a greater vertical displacement.

The trunk and direction of flight, often referred to as the angle of attack in the literature, was found to be significantly smaller for the more successful jumpers at the 55 meter mark. The value of a small angle of attack is confirmed in the literature, however the values found in this analysis are somewhat larger than those reported by Hubbard et al. (1989), Luhtanen (1995), and Puumala (1995). Hubbard recommends an ideal angle of attack close to 30°, while Puumala's 1995 study found the best jumpers to be maintaining an angle of 40° during the analyzed phase. The larger angles found for the Steamboat jumpers (mean = 51.4°) may be attributed to the skill level of the sample, the influence of the inclement weather conditions, and the measurement of the angle values in different positions of the overall flight curve. It is also important to note that for competitions on the smaller hills, the drag factor affects the jumper much less than on a large hill or ski flying hill. (Remizov, 1984). For this reason, it can be hypothesized that jumpers studied on smaller hills will also assume a larger angle of attack.

The variable ski and leg angle was shown to be significantly smaller for the best jumpers in the set of subjects who jumped over 69 meters. This is in accordance with the results of Watanabe and Watanabe (1993), who performed wind tunnel testing on a model of a ski jumper. They indicated that to optimize the distance jumped, the jumper should minimize the ski and leg angle, which has the beneficial aerodynamic effect of decreasing the vortex flow behind the jumper (Watanabe and Watanabe, 1993). The resulting reduction of drag forces on the jumper allows them to maintain velocity and remain in flight for a longer period of time. The ski jumpers who displayed a small ski and leg angle at the 55 meter mark of their flight were also seen to have a greater vertical displacement of the center of mass from the landing hill. A compact, forward flight position appears to be an important factor towards achieving a high flight trajectory and an aerodynamically efficient flight position.

The angle between the ski and leg angle at 55 meters for the top 25 jumpers was also correlated to the right arm and trunk. The moderate negative correlation illustrates a closer arm position for the jumpers maintaining a more forward flight position. Watanabe (1990) investigated the optimal arm position during flight in a wind tunnel, and found the position with the arms close to the body was most advantageous for all conditions of the ski angle.

The leg and direction of flight was another variable significantly related to the distance jumped. This negative correlation also verifies the importance of a forward flight position. Although the result described a weak relationship to the distance jumped, the leg and direction angle was moderately to strongly correlated with other important independent variables. The trunk and thigh angle was moderately related to the leg and direction of flight variable, indicative of the associated extension of the body in a forward flight position. The ski and leg angle was strongly related to the leg and direction angle. Interestingly, ski and leg angle and the trunk and thigh angle were not significantly correlated. This finding suggests that the ski and leg angle and the trunk and thigh angle each account for a different part of the variability in the leg and direction variable. Both variables contribute to the maintenance of a forward flight position, but are not dependent on one another.

Prediction of the Dependent Variable

A multiple regression model was derived which predicted the distance jumped, at the .05 level of significance. Two models were developed first using a full regression and then a stepwise method. Both of the regression models resulted in significant predictions and provided insight into the measured variables during the mid-flight phase.

The multiple correlation coefficient of $r = .7518$ for the full regression model was high and provided a good general model of the contribution of the variables of mid-flight and their overall contribution to the final result of the ski jump performance. The resulting prediction equation suggested that in order to maximize the distance jumped the athlete should (a) assume a flight position which incorporates a small angle between the ski and leg, (b) attempt to minimize the deceleration of the horizontal velocity, (c) increase the "V" angle between the skis, (d) assume a small angle between the trunk and ski, (e) increase the trunk and thigh angle and, (f) keep the legs slightly spread apart.

The stepwise analysis produced a similar model for predicting the distance jumped, using just four of the original variables. The multiple correlation coefficient obtained was equal to $r = .6811$. This value reflects the importance of the variables selected, since the predictability of distance jumped was only slightly decreased by using a smaller number of variables in the prediction equation. An important consideration, was that the two variables, change in horizontal velocity and angle of the skis "V" in the XZ plane were selected in the stepwise analysis as valuable predictors of the distance jumped, despite not being significantly correlated to the criterion variable.

The change in horizontal velocity was hypothesized to increase for the best jumpers during the mid-flight phase and to be an important contributor to the distance jumped (Puumala, 1995). The correlation results from this study do not support this theory, as the change in horizontal velocity was not significantly related to the distance jumped. The stepwise regression analysis did however, select the change in horizontal velocity as a significant predictor of the criterion variable, distance jumped. This indicates that, although not strongly related to the distance jumped, the change in horizontal velocity can be considered to explain some of the variance in the prediction.

The lack of any significant change in horizontal velocity for the best jumpers may be the result of several factors, or a combination of factors. One possibility is that a significant change in horizontal velocity is actually not a significant factor of ski jumping flight. However, the two studies of Jost (1995) and Puumala (1995) appear to support the existence of an increase in horizontal velocity during mid-flight. Another reason the jumpers may have tended to decelerate through the mid-flight in the present study was the relatively open flight position assumed by the jumpers. This open position included a wider ski and leg angle and a larger angle of attack, in comparison to the previous literature. The relatively open flight position may have been related to the weather conditions, which were far from ideal. A moderate tail wind prevailed throughout most of the competition, in addition to a snowfall. Jumpers are often unable to execute an aggressive flight phase due to the lack of air pressure below the body and the skis. It is the pressure of the air flow against the body and the skis that allows ski jumpers to assume a compact, efficient flight position.

According to the law of projectile motion, a change in velocity during flight can only be the result of gravity or air resistance. Since gravity affects the jumper vertically, it is the aerodynamic characteristics that may lead to an increase in horizontal velocity. This is analogous to a glider, which accelerates in the forward direction upon leaving the ground and tilting forward (Piggott, 1977). This forward position results in altering the flow of air around the glider, so that some vertical dropping occurs, but also some increase in the velocity in the forward direction. The force of gravity is converted to forward thrust due to the aerodynamic factors. This same effect seems to apply to the mid-flight of the best jumps, in ideal conditions. It appears that conditions for the present study were not conducive to this aerodynamic effect. Further study of the flight phase in ski jumping may reveal the relationship between the change in horizontal velocity and the distance jumped and the variables that contribute to that increase.

Structure of Relationships Among Selected Variables

The factor analysis performed on the set of data, which included the whole sample of competitors (n = 40), revealed valuable information about the groups of correlated variables for the analyzed section of mid-flight. The structure of the rotated factor loadings at 55 meters consisted of three factor loadings which explained 75.2% of jump length variance (see Table 14). The amount of variance in distance accounted for by a factor matrix of three factors is in very close accordance with the study performed by Vaverka et al. (1995). In Vaverka's study, the amount of explained variance for the jump length was 73, 83 and 87% measured at 59, 68 and 75 meters respectively (Vaverka et al., 1995).

The first factor extracted included strong loadings on six variables. These included distance, flight angle, ski and trunk angle, vertical displacement of the center of mass, angle between the ski "V" in the XZ plane and the angle between the ski and direction of flight. The six variables included in factor 1 each represent distinct characteristics of ski jump flight performance. Far from representing a single trait of the flight movement, factor 1 can be referred to as the <u>distance criterion factor</u>. This description is justified by the strong loading of the distance jumped on that factor and it's relationship with each of the other five factor loadings. Positive factor loadings for factor 1 are maximized in order to optimize the criterion, distance jumped. The displacement of the center of mass, the angle between the skis in the XZ plane, and the angle between the ski and the direction of flight should all be increased. Jumpers should also be encouraged to minimize both the flight angle and the angle between the ski and the trunk in order to increase the distance achieved.

Loadings for factor 2 included the strongly related velocity variables and the trunk and direction of flight variable which describes the angle of attack. Factor two can be referred to as the <u>angle of attack factor</u>. The relationship between the trunk and direction variable and both the horizontal and resultant velocities was a negative one. In order for the jumper to increase the two components of velocity, the angle of attack should be minimized. Similarly, the positive loading for the vertical velocity variable suggests that in order to minimize the velocity of the ascent to the landing hill, the angle of attack must also be minimized. A very small negative factor loading of the criterion variable for factor 2 indicates a very weak relationship between each of the strong factor loadings and the distance jumped. This weak factor relationship does not negate the impact factor 2 has on the variance of the sample. In fact, the trunk and direction of flight was moderately associated with the distance jumped, as seen in the correlational analysis. The trunk and direction variable was also correlated with the group of velocity variables, which resulted in their forming the angle of attack factor. It should be noted that the values of the velocity components were not significantly related to the distance jumped, but that the strong loadings seen for the angle of attack factor indicates their contribution to the overall variance of the sample.

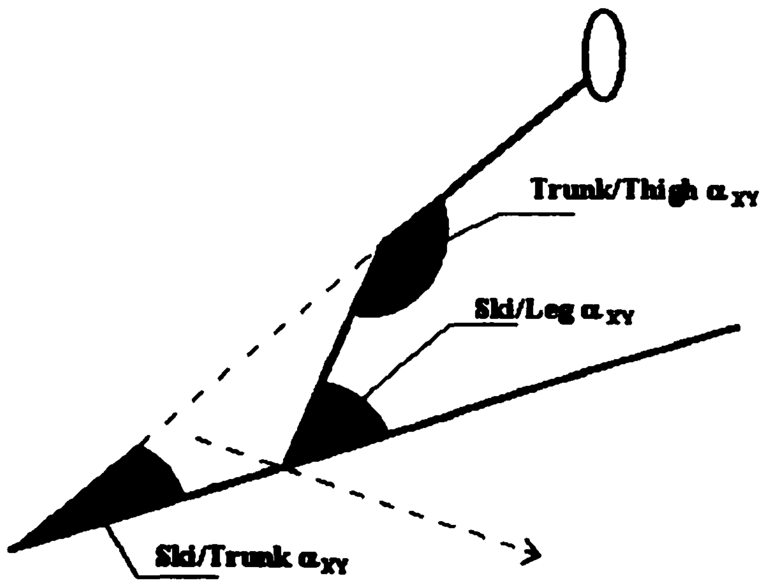
In a factor analysis performed by Vaverka et al. (1995) on the data collected on the Innsbruck K110 hill (at 68 meters), the velocity variables were not factored strongly with the trunk and direction of flight variable. In fact, the velocity variables were loaded on the third factor and were not grouped with any of the angle variables. This difference suggests that the trunk and direction of flight angle had a greater influence on the velocity at the 55 meter mark in Steamboat than at the 68 meter mark in Innsbruck. Qualitatively, the mean trunk and direction of flight angles were larger in the present study, than those described in Vaverka's Innsbruck study. A larger angle of attack may have had a greater influence on the aerodynamic characteristics of the ski jumper and the overall velocity.

The third factor contained strong loadings for the variables leg and direction of flight, ski and leg angle, and trunk and thigh angle. The combination of these variables are associated with the forward flight position during mid-flight. Factor 3 can be referred to as the flight position factor. Each of the three factor loadings were interpreted relative to a strong negative factor loading on the dependent variable, distance jumped. The positive loadings of the leg and direction variable and the ski and leg angle variable suggests that in order to maximize the distance jumped, jumpers should minimize their leg angle relative to the direction of flight and minimize the angle between the ski and the leg. The positive factor loading of the trunk and thigh angle illustrates the need to maximize the flatness of the body in a forward flight position. Attaining a forward flight position will give the jumper the most aerodynamically efficient flight position, which has minimal drag and a relatively good lift component.

Factor 3 represents variables that were similarly loaded in the study by Vaverka et al. (1995). This confirms that the same variables contribute to the forward flight position during mid-flight regardless of external conditions. The three variables of the flight position factor work together in attaining the position of the skier-ski system. The angle of the ski and direction of flight was not strongly loaded on the flight position factor, as it was in Vaverka's 1995 study. It is possible that the ski angle relative to the path of motion had less of a contribution to the flight position of the jumper in mid-flight. The moderate tail wind that was experienced by most of the jumpers during the competition in Steamboat may have played a role in the difference between the two factor loadings. Ski jumping with the wind coming from behind is very difficult for the jumpers who have much less air pressure ahead of them and especially below their skis. Without good air pressure below, the skis may tend to remain further away from the jumpers' body and have a negative influence on the aerodynamic quality of the flight position.

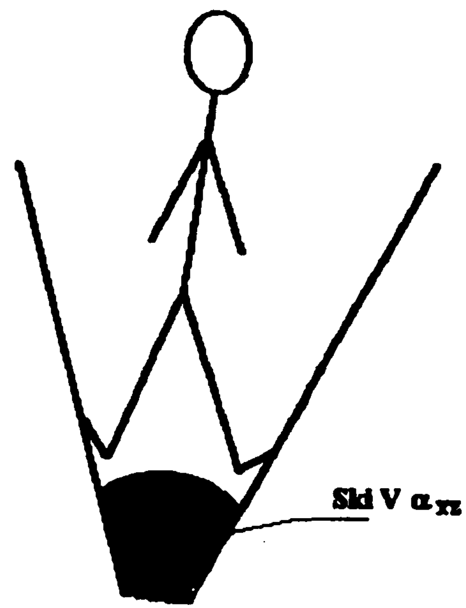
Results of the mid-flight phase indicate that ski jumpers must assume a compact, aerodynamic flight position in order to achieve the greatest possible distance at landing. This position includes a small angle of attack, a small ski and leg angle, a small ski and trunk angle, a large trunk and thigh angle, a wide 'V' angle of the skis, a large ski and direction of flight angle and a small leg and direction of flight angle. The results of the correlations seem to support the results of previous studies, despite the adverse weather conditions. The same combination of factors is related to the overall distance jumped, similar to different hills, under more favorable weather conditions. Some qualitative differences were noted for some of the variables, which contrast previous analyses. These observations seem to indicate that the jumpers in Steamboat flew with a much more open flight position. A more open flight position may been related to the tail wind, which resulted in the very short distances achieved on the landing hill.

Factor Analysis of the Mid-Flight Phase (55m)



Tendencies:	Trunk/Thigh α_{XY}	MAX
	Ski/Leg α_{XY}	MIN
	Ski/Trunk α_{XY}	MIN

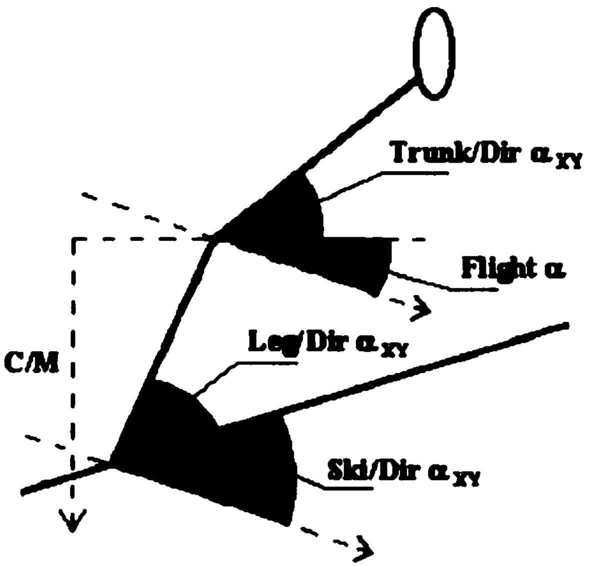
Figure 6a. Variables in the XY Plane Relating to Distance Jumped.



Tendencies: Ski V α_{XZ} MAX

Figure 6 b. Variable in the XZ Plane Relating to Distance Jumped.

Factor Analysis of the Mid-Flight Phase (55m)



Tendencies:	Trunk/Dir α_{XY}	MIN
	Flight α	MIN
	Ski/Dir α_{XY}	MAX
	Leg/Dir α_{XY}	MIN
	Displ. C/M	MAX

Figure 6c. Direction of Flight Variables Relating to Distance Jumped

Discussion

Preparation for Landing

The discussion of the results obtained for the preparation for landing analysis will be presented under the following headings: (a) relationship to the dependent variable, distance jumped, (b) prediction of the dependent variable and, (c) structure of the relationships among selected variables.

Relationship to the Dependent Variable

The correlation matrix developed for the preparation for landing variables of the whole sample of jumpers 12 frames prior to landing provided some interesting information about the relationships between variables. It was previously thought that the jumpers who achieved the greatest distance would complete the preparation for landing phase with a slower descent to the landing hill. It was hypothesized that the more successful jumpers utilized a position which increased the lift and decreased the vertical velocity during the final phase of flight.

Contrary to expectations, the vertical velocity demonstrated a strong negative relationship with the distance jumped. (See figure 7). This may be due to the better jumpers being able to hold an efficient flight position longer and executing the landing movement in a shorter period of time. It is very interesting to note the strong correlation with vertical velocity since it was thought that better jumpers may be able to achieve greater lift until the final heel contact with the ski on the landing hill. However, this hypothesis is strongly refuted by the observed results which shows a faster descent to the landing hill for the best jumpers.

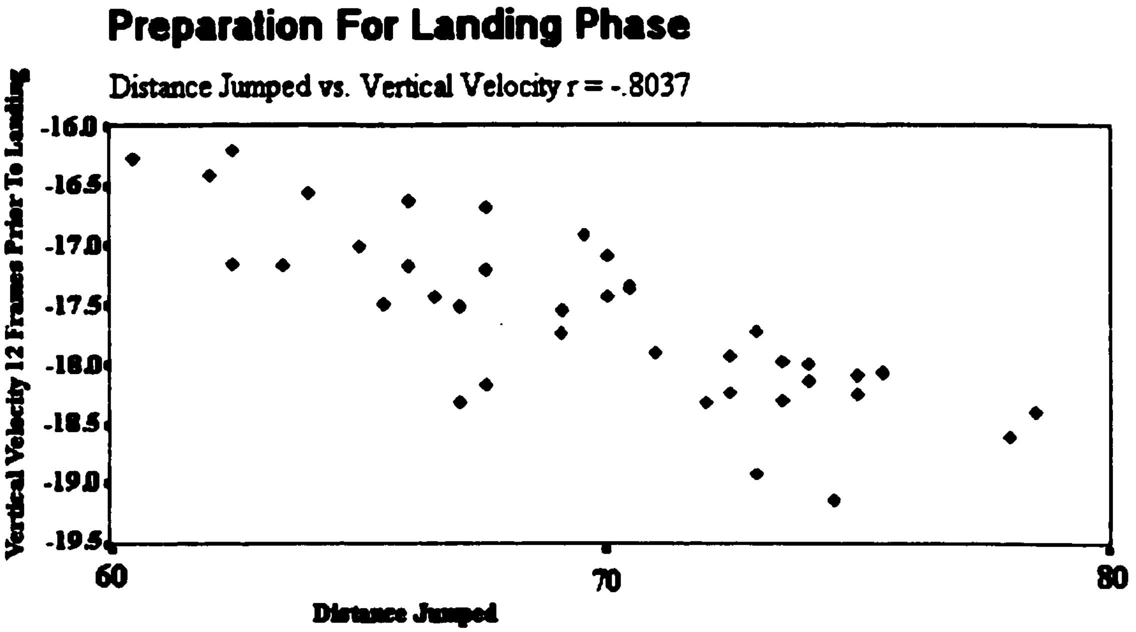


Figure 7. Scatterplot of Distance Jumped Versus Vertical Velocity.

The relationship of the angle of the flight curve with the distance jumped shows a similar tendency. A moderate positive correlation with the distance jumped suggests that the more successful jumpers entered the preparation for landing phase with a sharp downward flight angle. A sharper, faster descent to the landing hill suggests that the best jumpers are able to hold an efficient flight position longer, thus achieving a greater distance in the final stages of flight. The combination of a downward flight angle and a greater vertical velocity indicated that the best jumpers did not gain the extra distance during the preparation for landing phase, as was expected. A greater lift component during this phase would have been indicated by a slower descent to the landing hill. The opposite result observed in the present analysis may reveal that the best jumpers continued to gain maximum lift until immediately preceding the preparation for landing phase.

A significant but weak relationship was observed which may suggest that the more successful jumpers entered the preparation for landing phase from a higher vertical displacement. Examination of the results for the smaller sample size of n = 21 jumpers (jumpers who landed further than 70 meters) indicated that the vertical displacement of the center of mass from the landing hill was significantly greater for the jumpers who landed further down the hill. The lack of strength of the relationship between vertical displacement and distance jumped shows that the height of the flight curve in the final stage of flight is not as crucial to performance as during the mid-flight phase. Some athletes who achieved greater distances may have had good vertical displacement during an earlier phase of flight, but did not maintain it until the end of the flight. The weak correlation of the vertical displacement of the center of mass to distance jumped can be explained by the multitude of factors which influence the final result of the jump. Jumpers who entered the preparation for landing phase from a higher vertical displacement may have had a good performance in the final phase of flight, but may have had problems on the take-off or during the early stages of flight. The results do suggest, however, that of the jumpers achieving greater distance, some may have been able to gain extra distance by optimizing critical factors during the final stages of flight.

The independent variable trunk and ski angle also showed a weak to moderate correlation with the distance jumped. Intuitively the opening of the flight position should be related to greater distance achieved on the landing hill. It is believed that by opening the angle between the trunk and skis, the lift to drag ratio (l/d) is increased, giving the jumper an extra boost at the end of the flight. From the subset of jumpers (n = 21) who jumped 70 meters or greater, the vertical displacement was also related to the ski and trunk angle. The jumpers who had the more open position of the trunk and skis, were higher at .204 seconds before their heel contact with the snow on the landing hill.

A more open flight position, characterized by a greater trunk and ski angle, is often associated with a position of maximal lift. However, as the position opens up to a certain point, the beneficial effects of the lift are negated by the onset of tremendous drag forces. It is possible that the best jumpers held a flight position during the late stages of their flight which gained the most lift. As they moved into the preparation for landing phase, this position was opened to the point where drag forces would tend to overcome the lift forces and bring the jumper quickly to the landing slope. This quick descent is often referred to as stalling, which occurs when an airfoil reaches too large an angle of attack. Airflow above the wing or airfoil becomes turbulent, reducing lift and increasing the drag (Piggott, 1977). The quick descent is described by the strong relationship between vertical velocity and the distance jumped.

Other interesting correlations included the correlations of independent variables, measured six frames prior to landing, with the decrease in the right knee angle. While the knee bend itself was not significantly related to the distance jumped, it was related to some independent variables that were related to the dependent variable. Two strongly inter-related variables, trunk and thigh angle and the trunk and ski angle, were both positively related to the angle of the right knee. As the right knee was flexed, the trunk and thigh tended to bend and the angle between the ski and trunk decreased. The angle of the right knee was also a significant factor in the angle between the ski and leg. As the knee was flexed, the ski and leg angle also decreased. However, decreasing this angle during the preparation for landing does not have the same aerodynamic effect as during the mid-flight: It may actually indicate a movement of the skis upward. Since the leg segment for the ski and leg angle variable consists of a line between the right hip and right ankle, the angle does not change directly as a result of the knee flexion. The angle of the ski and leg decreases as a result of decreasing angles of the two pivot points, the knee joint, and the articulation between the ski boot and the binding on the ski. It is also important to note that, while both the trunk and thigh angle and the ski and trunk angle were significantly related to the distance jumped, the ski and leg angle was not. So, while the flexion of the right knee may play an important role in the positioning of the skier-ski system in preparation for landing, the importance of the angle between the ski and leg is not seen as critical to success in this phase.

Virmavirta and Komi (1991) alluded to the difficulty of maintaining a good flight position until the last possible moment. It appears as though the best jumpers were able to do this; they were beginning the preparation for landing from a higher position, partially due to holding an effective flight position for a longer period of time and gaining valuable lift until the last possible moment. The angular displacement variables indicated that the best jumpers were in a more open flight position, with a more open trunk and thigh angle, a more open ski and trunk angle and flexed their knees in preparation for landing later. An open position was advantageous in increasing the lift for the jumper in the final stages of flight. An open position may have slowed the jumpers downward descent during the phase immediately preceding the preparation for landing, but is actually related to a stalling effect during the final phase of flight. This phenomenon is thought to have increased the vertical velocity in the negative direction for the best jumpers during the final flight phase.

Prediction of the Dependent Variable

A multiple regression model was also developed for the preparation for landing analysis, in order to predict the distance jumped, at the .05 level of significance. Two models were developed to assess the total predictability of distance jumped by using the analyzed variables at 12 frames before landing. Each of the regression models provided useful information on the critical features associated with the preparation for landing phase.

The full regression model included six variables which accounted for 74.71% of the variance in distance jumped. The stepwise model selected just three of the original six variables to account for 74.23% of the distance jumped. Compared to the regression analysis performed on the mid-flight variables, the preparation for landing variables were able to predict distance jumped with greater accuracy with less variables. Statistically, it can be said that the variables of the preparation for landing reflect more strongly the characteristics of the criterion variable, distance jumped. As we move closer to the landing itself, the variables tend to reflect the distance achieved with a greater accuracy. It is important to recognize that while the predictability increases closer to the criterion, the importance of the previous phases is not diminished. In fact, the opposite is true: the previous phases of the jump result in the observed performance during the preparation for landing. The variables of the preparation for landing then reflect an accumulation of the predictability in the criterion variable. The three variables selected to most effectively predict distance jumped, from .204 seconds before landing, were vertical velocity, flight angle and the angle formed between the ski and trunk. Prediction of the distance jumped is most easily and accurately assessed by the velocity of the descent to the landing, the direction of flight to the landing and the positioning of the skier and the skis. In order to increase the distance jumped through the preparation for landing phase, athletes should gain maximal lift during the phase preceding the preparation for landing, in order for them to (a) descend most quickly to the landing hill, (b) descend at a sharper angle towards the landing, and (c) use an open skier-ski system, characterized by a large trunk and ski angle.

Structure of the Relationships Among Selected Variables

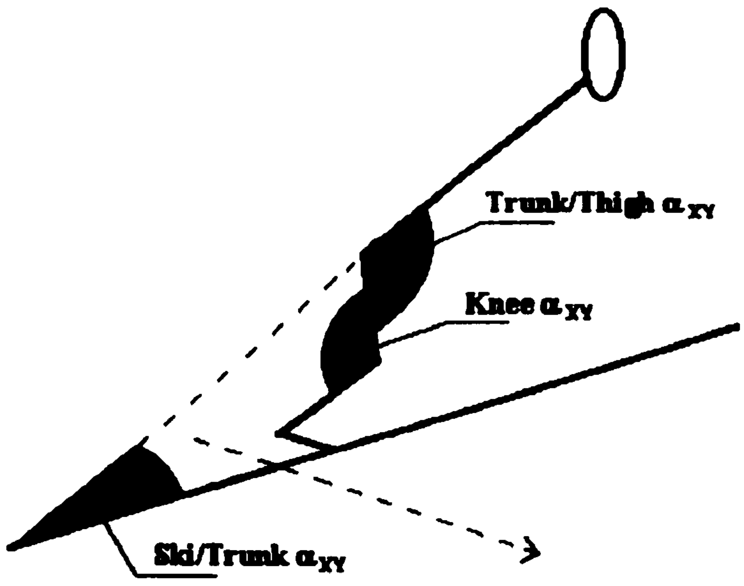
A factor analysis was conducted using eight of the preparation for landing variables and explained 74.7 percent of the sample variance through three varimax rotated factors. Each of the factors gives insight into the complex intercorrelations of the variables it contains. The factor analysis used the entire sample of 40 jumpers.

Factor one included strong loadings on the distance, flight angle and vertical velocity. As in the mid-flight analysis, the first factor contained the distance jumped. As distance jumped is the criterion variable of the study, factor one will be referred to as the distance criterion factor. The factor of the criterion highlights the variables that are most strongly correlated with the distance jumped. In the case of the preparation for landing factor analysis, both the flight angle and the vertical velocity were loaded strongly with the distance jumped. This confirms the findings of the correlational analysis and the regression analysis, which found that the best jumpers were entering the preparation for landing phase higher, while coming out of flight at a sharper angle downward, with a greater negative vertical velocity. The vertical distance of the center of mass from the landing was not included in the factor analysis, since the results were not directly comparable for jumps shorter that 70 meters. It is believed, however, due to the correlations of the height variable with both the distance jumped and the vertical velocity, that the vertical displacement of the center of mass from the landing would have been loaded with the distance criterion factor.

Factor two contained strong factor loadings for the right knee bend angle and the trunk and thigh angle. In addition, the change in horizontal velocity was loaded negatively on the second factor. This negative factor loading suggests that maximizing the knee angle and the trunk and thigh extension will be accompanied by a related decrease in horizontal velocity. Factor two can be referred to as the body extension factor. As the body opens up, the increased drag on the frontal surface of the jumper results in a decrease of the horizontal velocity. Relative to the small positive factor loading of distance jumped for factor 2, the knee angle and trunk and thigh angle should be maximized with the associated decrease, or minimization of horizontal velocity.

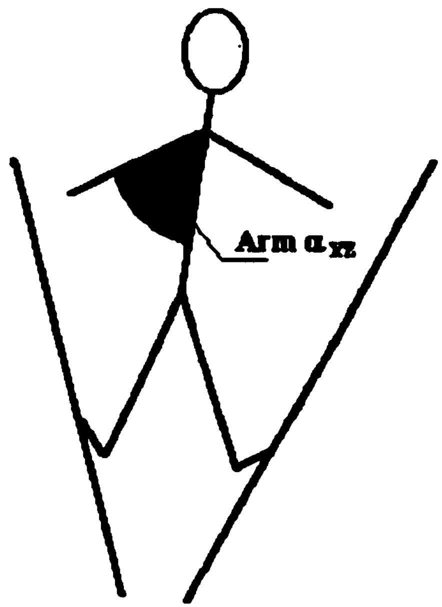
Factor three contained strong factor loadings for two variables, the ski and trunk angle and the angle of the right arm from the trunk. The third factor can be referred to as the skier-ski position factor, since both variables refer to the positioning of the skier-ski system. The angle between the skis and the trunk was more open for the more successful jumpers, who were also observed to hold their arms closer to the body through this phase.

Factor Analysis of the Preparation For Landing Phase
(12 Frames Prior to Landing)



Tendencies:	Trunk/Thigh α_{XY}	MAX
	Knee α_{XY}	MAX
	Ski/Trunk α_{XY}	MAX

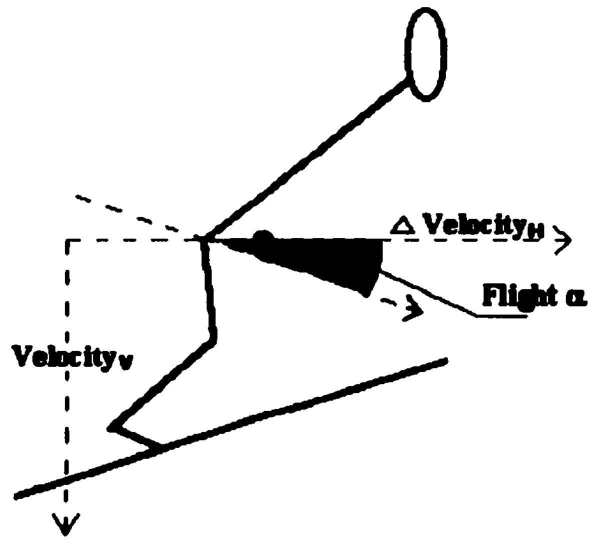
Figure 8a. Variables in the XY Plane Relating to Distance Jumped.



Tendencies: Arm α_{XZ} MIN

Figure 8b. Variable in the XZ Plane Relating to Distance Jumped.

Factor Analysis of the Preparation For Landing Phase (12 Frames Prior to Landing)



Tendencies:	Velocity$_V$	MAX
	Flight α	MAX
	△ Velocity$_H$	MIN

Figure 8c. Direction of Flight Variables Relating to Distance Jumped

Loadings on the third factor are interpreted in relation to the negative factor loading on the distance jumped loading. The negative loading of the ski and trunk variable is thus maximized to increase the distance jumped, while the arm angle should be minimized.

The percentage of the sample variance accounted for by the three factors was approximately 75% (see Table 14). While the result of the present factor analysis is not directly comparable to the 1995 study of Vaverka et al., it is valuable to note the continued high value of explained variance during the final instant of the flight phase. The result appears to agree with Vaverka's assertion that the explained variance of the jump length increases toward the end of flight (Vaverka et al., 1995).

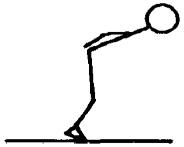
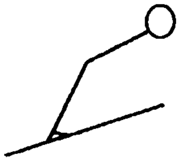
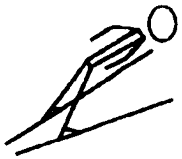
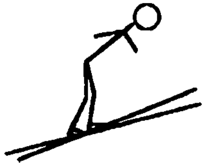
The combination of an open position of the skier-ski system and the higher vertical displacement of the center of mass at the beginning of the preparation for landing phase suggests that the best jumpers were approaching this phase in an open position. An open flight position is associated with increased lift and has been suggested as being the best position to assume during the later stages of flight (Remizov, 1984). The compact flight position observed for the best jumpers during the mid-flight phase indicates that the jumpers achieving the greatest distance did not assume a position with an associated increase in lift until after the analyzed fieldwidth for the mid-flight analysis.

It is of some interest to note that the more successful jumpers, who opened up the ski and trunk angle at the beginning of the preparation for landing phase, also maintained an arm position close to the trunk. It is of considerable importance for the jumper to extend the arms straight out upon landing, not only to maintain balance on the landing, but to receive full style points. In the traditional telemark landing, the arms are held out from the body, while one foot is placed forward. Judges award style points based on the quality of this landing, including the positioning of the arms. It may be that the extension of the arms during landing is both a learned response to achieve good style points and a reflex initiated in order to maintain balance. It would appear that the best jumpers are able to delay this arm extension in order to maintain optimal flight characteristics as long as possible.

The analysis of the preparation for landing phase provided valuable insight into the final stage of ski jumping flight. Best jumpers were observed to maintain an open flight position, including a small ski and trunk angle, a large trunk and thigh angle, a large knee angle and a small arm angle. This open position was maintained while descending to the landing hill more quickly and at a sharper angle. This result contradicted the initial hypothesis of the best jumpers gaining lift during the final flight phase. Results of the present study also seem to support the use of an open flight position in the last stage of flight immediately before the preparation for landing phase. An open position is thought to increase the lift component on the skier-ski system and increase the distance jumped. During the preparation for landing phase, the best jumpers opened the flight position beyond the critical angle of attack, after which stalling occurs. This stalling effect brought these jumpers to the landing hill in a relatively short amount of time, but allowed them to maintain an efficient flight position for a long as possible.

Table 14

PERCENTAGE OF SAMPLE VARIANCE ACCOUNTED FOR THROUGH FACTOR ANALYSIS

SKI JUMPING PHASES		 INRUN	 TAKE-OFF		 TRANSITION				 FLIGHT I			 FLIGHT II			 PREPARATION FOR LANDING
Distance From Edge (m)		-18	-4	0	1.8	5.6	6.5	12.5	15	20	25	59	68	75	
Percentage	CZE (2D)*	0.32	0.33	0.19		0.36									
Of	SLO (2D)*				0.53		0.30								
Sample	(3D)*						0.44	0.32							
Variance	CAN (2D)*								0.17	0.42	0.45	0.73	0.83	0.87	
Distance From Edge (m)												55			
Time Before Landing (s)															0.204
%	CAN (3D)**											0.75			0.75

* Innsbruck 1995, K120 (Vaverka et al., 1995)
** Steamboat Springs 1996, K90

Chapter 6

Summary, Findings, Conclusions, Recommendations

Summary

The purpose of this study was to first identify and quantify specific kinematic variables of both the mid-flight and the preparation for landing phases. Secondly, the study sought to examine the statistical contribution of variables in both phases to the distance jumped. Finally, the study attempted to develop a model which would provide a general view of the structure of the relationships among analyzed variables.

Experimental Procedures

The subjects for this investigation were 50 highly skilled nordic combined competitors participating in the 1996 World Cup K-88 event. Forty trials from the first round of competition were selected for inclusion in the data analysis.

The data for the 40 analyzed subjects was collected using two cameras mounted on Peak Performance Pan and Tilt Heads. The jumpers were taped as they passed through the field of view, from 55 to 85 meters on the jump hill. The Pan and Tilt hardware enabled the data to be collected over a wide field of view, which resulted in the analysis of both the mid-flight and preparation for landing phases. Values for the distance jumped and the inrun velocity were collected from the official results printed by the FIS competition committee.

The Peak Performance 3D Video Analysis System was used to extract the horizontal and vertical coordinates for a 19 point segmental model. The center of mass was calculated for the model, which included the masses of skis, helmet and boots. Data was smoothed and processed to compute linear displacements and velocities and angular displacements in the three planes of motion. Statistical treatment of the raw kinematic data was performed using the appropriate computer programs from SPSS.

Findings

The findings of the two analyses conducted during this investigation are summarized under the following headings:

a) Relationship between selected variables and distance jumped, b) Prediction of the dependent variable, and c) Structure of the relationships among selected variables.

Mid-flight

Relationship between selected variables and distance jumped.

The following independent variables significantly correlated with distance jumped for the sample of the top 25 jumpers, at 55 meters:

1. Vertical displacement of the center of mass (Displ. c/m) (strong).
2. The trunk and direction of flight angle (Trunk/Dir α_{XY}) (moderate).
3. The ski and trunk angle (Ski/Trunk α_{XY}) (moderate).
4. The ski and leg angle (Ski/Leg α_{XY}) (moderate).
5. The leg and direction of flight (Leg/Dir α_{XY}) (weak).
6. The direction of flight angle (Flight α) (weak).
7. The velocity in the inrun ($Velocity_{IR}$) (weak).

Prediction of the Dependent Variable

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

$$Y' = 54.7574 - .2100X_1 + .6847X_2 + .2317X_3 - .1437X_4 + .1156X_5 + .0687X_6$$

where:

Y' = Dependent variable (Distance)

X_1 = Ski/Leg α_{XY}

X_2 = ΔVelocity$_H$

X_3 = Ski V α_{XZ}

X_4 = Ski/Trunk α_{XY}

X_5 = Trunk/Thigh α_{XY}

X_6 = Legs α_{XZ}

2. A stepwise regression model for predicting the distance jumped was derived. The equation for predicting the distance jumped, with variables arranged in the order of their importance to the prediction, was:

$$Y' = 75.5741 - .1334X_1 - .2298X_2 + .6781X_3 + .2165X_4$$

where:

Y' = Dependent variable (Distance)

X_1 = Ski/Trunk α_{XY}

X_2 = Ski/Leg α_{XY}

X_3 = ΔVelocity$_H$

X_4 = Ski V α_{XZ}

Structure of the Relationships Among Selected Variables

1. Three factors were extracted from the 13 variables, to explain 75.2% of the variance in the sample of 40 jumpers at 55 meters.

2. Factor 1 included strong factor loadings for the variables distance jumped (+), ski and direction of flight angle (+), ski angle (XZ plane) (+), vertical displacement of the center of mass (+), flight angle (-) and the ski and trunk angle (-).

3. Factor 2 included strong loadings for the horizontal and resultant velocities (-), the vertical velocity (+) and trunk and direction variable (+).

4. Factor 3 included strong loadings of the leg and direction of flight (+), the ski and leg angle (+), and the trunk and thigh angle (-).

Preparation for Landing

Relationship between selected variables and distance jumped

The following independent variables significantly correlated with distance jumped for the sample of 40 jumpers, at 12 frames prior to landing:

1. The vertical velocity of the center of mass ($Velocity_V$) (strong).
2. The flight angle (Flight α) (moderate).
3. The ski and trunk angle (Ski/Trunk α_{XY}) (weak).
4. The trunk and thigh angle (Trunk/Thigh α_{XY}) (weak).

The following independent variables significantly correlated with distance jumped for the sample of 21 jumpers, at 12 frames prior to landing:

1. The vertical displacement of the center of mass from the landing hill (Displ. C/m) (weak).

Prediction of the Dependent Variable

1. The full multiple regression equation for predicting the distance jumped from the entire sample of 40 jumpers, 12 frames prior to landing, with the variables arranged in the order of their importance was:

$$Y' = 54.6983 - 3.6103X_1 + 1.4070X_2 + .0857X_3 + .0243X_4 - .0076X_5 + .0131X_6$$

where:

Y' = Dependent variable (distance jumped)

X_1 = Velocity$_V$

X_2 = Flight α

X_3 = Ski/Trunk α_{XY}

X_4 = Trunk/Thigh α_{XY}

X_5 = Arm α_{XZ}

X_6 = Ski/Leg α_{XY}

2. A stepwise regression model for predicting the distance jumped was derived. The equation for predicting the distance jumped, with variables arranged in the order of their importance to the prediction, was:

$$Y' = -54.0320 - 3.6512X_1 + 1.4180X_2 + .1207X_3$$

where:

Y' = Dependent variable (Distance)

X_1 = Velocity$_V$

X_2 = Flight α

X_3 = Ski/Trunk α_{XY}

Structure of the Relationships Among Selected Variables

1. The factor analysis extracted three factors from the 8 variables included in the analysis, to explain 74.7% of the variance in the sample of 40 jumpers, 12 frames prior to landing.

2. Factor 1, included strong loadings for the length of jump (Distance) (+), flight angle (Flight α) (+), and vertical velocity (Velocity$_V$) (-).

3. Factor 2 included strong loadings for the right knee angle (+), the trunk and thigh angle (+), and the change in horizontal velocity (-).

4. Factor 3 included strong loadings for the right arm angle (+), and the ski and trunk angle (-).

Conclusions

1. Athletes who achieved the longest jumps displayed a greater vertical displacement of the center of mass throughout the analyzed phases than their less successful competitors. This was thought to be the result of the multitude of kinematic factors leading up to each analyzed phase of flight.

2. Mid-flight- The results of both the regression analysis and the factor analysis performed on the variables at 55 meters of flight suggest that maximizing the distance jumped should involve (a) a small flight angle, (b) minimal deceleration of the horizontal velocity, (c) a greater vertical displacement of the center of mass, (d) assuming a flight

position with a small angle between the ski and leg, (e) increasing the angle between the "V" angle of the skis, (f) a small angle between the trunk and ski, (g) a greater trunk and thigh angle, (h) a small angle between the body segments and the direction of flight and, (i) a large angle between the skis and the direction of flight.

3. Preparation for Landing - The results of both the regression analysis and factor analysis performed 12 frames prior to landing suggest that the best jumpers displayed a) a greater negative vertical velocity, b) a steeper flight angle, c) a more open trunk and thigh angle, d) a more open ski and trunk angle, e) a more straight angle of the knee, f) a closer arm position relative to the trunk, and g) a decrease in horizontal velocity.

4. The factor analysis provided a way of simplifying the interpretation of the complex correlations between the variables by grouping variables into intercorrelated or associated factors. This method of statistical analysis is seen to be valuable in presenting important findings to coaches and athletes in a practical format. Three factors were extracted from the variables for each of the mid-flight and preparation for landing analyses. The three factors accounted for 75.2 and 74.7 percent of the sample variance in each phase respectively. Application of the factor analysis findings in the practical setting may be done through the interpretation of factors and the corresponding loadings (minimized or maximized) of specific variables. Coaches will be able to interpret factors which represent specific traits that may be developed by the athletes.

5. The performance of the flight phase was seen to be dependent on the kinematic characteristics displayed both during and leading up to each analyzed phase. The weather

conditions, including wind and snow conditions, had an effect on all of the measured variables and played a large role in the overall success of the jumps.

6. Despite less than ideal conditions for jumping, the general flight tendencies reported in previous studies were confirmed.

Recommendations

The following recommendations are offered for future research:

1. The complete flight phase of ski jumping should be studied, from the end of the take-off to the landing, with phases defined on the percentage of total distance jumped.

2. It is recommended that a thorough examination of the ski jump phases be performed in three dimensions in order to confirm the communality values observed by Vaverka et al. (1995) and the results of the present analysis.

3. The results of the present study should be confirmed on a K90 and/or K120 meter hill under normal weather conditions.

4. The variable change in horizontal velocity is hypothesized to be increased by the best jumpers under ideal conditions. The optimization of this effect may be of benefit to the distance jumped and warrants further study.

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Appendix A

Mean Performance Measures

Mid-flight Analysis For All Variables

Table 15

Mean Performance Measures

Mid-flight Analysis For All Variables (N=40)

Variable	Mean	Std Dev	Min.	Max.	N	Label
DISTANCE	70.26	4.53	62.0	78.5	40	Distance Jumped
$Velocity_R$	87.03	.48	85.85	88.13	40	Inrun Velocity
Δ $Velocity_H$	1.91	1.88	-1.107	7.273	40	Change in Hor. Velocity 50m-60m
Trunk/Thigh α_{XY} 50	162.54	9.25	143.440	187.967	40	Trunk and Thigh Angle 50m
Trunk/Thigh α_{XY} 55	160.74	12.53	118.156	176.213	40	Trunk and Thigh Angle 55m
Trunk/Thigh α_{XY} 60	146.76	29.56	56.353	176.783	40	Trunk and Thigh Angle 60m
Ski/Leg α_{XY} 50	24.08	8.15	10.434	44.554	40	Ski and Leg Angle at 50m
Ski/Leg α_{XY} 55	27.07	7.47	11.570	45.689	40	Ski and Leg Angle at 55m
Ski/Leg α_{XY} 60	33.15	8.35	17.800	50.781	40	Ski and Leg Angle at 60m
Ski/Trunk α_{XY} 50	15.52	5.94	4.603	24.788	40	Ski and Trunk Angle 50m
Ski/Trunk α_{XY} 55	18.63	6.93	4.988	31.475	40	Ski and Trunk Angle 55m
Ski/Trunk α_{XY} 60	23.84	8.31	7.585	41.012	40	Ski and Trunk Angle 60m
Ski V α_{XZ} 50	21.41	6.47	5.746	36.279	40	Ski and Ski Angle at 50m
Ski V α_{XZ} 55	19.73	6.38	6.132	34.140	40	Ski and Ski Angle at 55m
Ski V α_{XZ} 60	15.25	6.94	.923	26.729	40	Ski and Ski Angle at 60m
Legs α_{XZ} 50	12.95	7.10	.881	37.898	40	Leg and Leg Angles at 50m
Legs α_{XZ} 55	12.07	8.73	-3.839	39.989	40	Leg and Leg Angle at 55m
Legs α_{XZ} 60	12.24	9.08	.927	46.665	40	Leg and Leg Angle 60m
Arm α_{XZ} 50	17.05	5.15	8.0340	28.9680	40	Right Arm Angle at 50m
Arm α_{XZ} 55	19.84	8.71	.8086	52.2130	40	Right Arm Angle at 55m
Arm α_{XZ} 60	34.32	26.60	4.637	128.710	40	Right Arm Angle at 60m
Ski/Dir α_{XY} 50	36.27	5.93	20.135	44.347	40	Ski and Direction of Flight 50m
Ski/Dir α_{XY} 55	33.10	6.28	13.217	43.051	40	Ski and Direction of Flight 55m
Ski/Dir α_{XY} 60	29.21	7.40	12.506	41.681	40	Ski and Direction of Flight 60m
Leg/Dir α_{XY} 50	63.54	6.54	52.390	78.960	40	Leg and Direction of Flight 50m
Leg/Dir α_{XY} 55	64.54	7.75	49.178	80.134	40	Leg and Direction of Flight 55m
Leg/Dir α_{XY} 60	73.03	14.16	53.363	113.00	40	Leg and Direction of Flight 60m
Trunk/Dir α_{XY} 50	51.47	5.08	42.278	61.418	40	Trunk and Direction of Flight 50m
Trunk/Dir α_{XY} 55	51.40	4.68	41.518	62.431	40	Trunk and Direction of Flight 55m
Trunk/Dir α_{XY} 60	52.97	5.66	40.363	61.034	40	Trunk and Direction of Flight 60m
$Velocity_H$ 50	19.71	1.85	14.383	22.204	40	Horizontal Velocity at 50m
$Velocity_H$ 55	21.29	.74	19.888	23.114	40	Horizontal Velocity at 55m
$Velocity_H$ 60	21.62	.66	20.050	22.883	40	Horizontal Velocity at 60m
Flight α 50	-35.49	1.11	-38.948	-33.870	40	Direction of Flight Angle 50m
Flight α 55	-36.20	.71	-37.980	-34.779	40	Direction of Flight Angle 55m
Flight α 60	-37.93	.87	-41.012	-36.254	40	Direction of Flight Angle 60m
Displ. C/M 50	1.65	.34	.931	2.274	40	Vertical Displacement of C/M 50m
Displ. C/M 55	1.44	.41	-.073	2.229	40	Vertical Displacement of C/M 55m
Displ. C/M 60	1.21	.33	.653	1.979	40	Vertical Displacement of C/M 60m

Table 16

Mean Performance Measures

Mid-flight Analysis For All Variables (N=25)

Variable	Mean	Std Dev	Min.	Max.	N	Label
DISTANCE	73.14	2.76	69.0	78.5	25	Distance Jumped
$Velocity_R$	87.17	.43	86.40	88.13	25	Inrun Velocity
Δ $Velocity_H$	1.93	1.78	-.386	7.273	25	Change in Hor. Velocity 50m-60m
Trunk/Thigh α_{XY} 50	163.25	7.67	143.900	177.923	25	Trunk and Thigh Angle 50m
Trunk/Thigh α_{XY} 55	165.96	6.31	153.077	176.213	25	Trunk and Thigh Angle 55m
Trunk/Thigh α_{XY} 60	162.90	8.91	141.775	176.783	25	Trunk and Thigh Angle 60m
Ski/Leg α_{XY} 50	23.47	7.37	10.434	39.674	25	Ski and Leg Angle at 50m
Ski/Leg α_{XY} 55	26.44	7.31	13.819	44.953	25	Ski and Leg Angle at 55m
Ski/Leg α_{XY} 60	30.42	7.34	17.936	47.454	25	Ski and Leg Angle at 60m
Ski/Trunk α_{XY} 50	13.68	5.72	4.603	24.788	25	Ski and Trunk Angle 50m
Ski/Trunk α_{XY} 55	16.22	6.48	4.988	26.185	25	Ski and Trunk Angle 55m
Ski/Trunk α_{XY} 60	21.30	7.60	7.585	34.207	25	Ski and Trunk Angle 60m
Ski V α_{XZ} 50	22.46	5.23	12.803	35.149	25	Ski and Ski Angle at 50m
Ski V α_{XZ} 55	20.76	4.90	9.534	30.911	25	Ski and Ski Angle at 55m
Ski V α_{XZ} 60	18.35	5.69	6.451	26.729	25	Ski and Ski Angle at 60m
Legs α_{XZ} 50	13.00	7.98	.881	37.898	25	Leg and Leg Angles at 50m
Legs α_{XZ} 55	13.92	9.22	1.325	39.989	25	Leg and Leg Angle at 55m
Legs α_{XZ} 60	13.16	10.20	2.406	46.665	25	Leg and Leg Angle 60m
Arm α_{XZ} 50	16.31	5.65	8.034	28.968	25	Right Arm Angle at 50m
Arm α_{XZ} 55	18.66	6.84	10.346	40.428	25	Right Arm Angle at 55m
Arm α_{XZ} 60	23.80	14.48	4.637	65.805	25	Right Arm Angle at 60m
Ski/Dir α_{XY} 50	37.43	4.93	25.445	44.347	25	Ski and Direction of Flight 50m
Ski/Dir α_{XY} 55	35.16	5.06	23.885	43.051	25	Ski and Direction of Flight 55m
Ski/Dir α_{XY} 60	32.82	5.38	22.000	41.681	25	Ski and Direction of Flight 60m
Leg/Dir α_{XY} 50	63.46	6.46	53.908	78.960	25	Leg and Direction of Flight 50m
Leg/Dir α_{XY} 55	62.92	6.76	51.288	78.901	25	Leg and Direction of Flight 55m
Leg/Dir α_{XY} 60	66.41	7.53	53.363	83.435	25	Leg and Direction of Flight 60m
Trunk/Dir α_{XY} 50	50.78	4.44	43.515	61.167	25	Trunk and Direction of Flight 50m
Trunk/Dir α_{XY} 55	51.07	4.63	41.518	62.431	25	Trunk and Direction of Flight 55m
Trunk/Dir α_{XY} 60	53.68	4.68	44.573	61.034	25	Trunk and Direction of Flight 60m
$Velocity_H$ 50	19.70	1.83	14.701	22.204	25	Horizontal Velocity at 50m
$Velocity_H$ 55	21.39	.77	19.888	23.114	25	Horizontal Velocity at 55m
$Velocity_H$ 60	21.63	.54	20.860	22.705	25	Horizontal Velocity at 60m
Flight α 50	35.24	1.07	33.870	37.655	25	Direction of Flight Angle 50m
Flight α 55	35.90	.64	34.779	36.978	25	Direction of Flight Angle 55m
Flight α 60	37.59	.68	36.254	38.775	25	Direction of Flight Angle 60m
Displ. C/M 50	1.83	.25	1.409	2.274	25	Vertical Displacement of C/M 50m
Displ. C/M 55	1.66	.23	1.191	2.229	25	Vertical Displacement of C/M 55m
Displ. C/M 60	1.40	.24	1.011	1.979	25	Vertical Displacement of C/M 60m

Appendix B

Mean Performance Measures

Preparation For Landing Analysis For All Variables

Table 17

Mean Performance Measures

Preparation For Landing Analysis For All Variables (N=40)

Variable	Mean	Std Dev	Min.	Max.	N	Label
Δ $Velocity_H$	.62	.87	-.875	2.532	40	Change In Horizontal Vel. 12 - land
DISTANCE	69.75	4.61	60.5	78.5	40	Distance Jumped
Flight α 12	-39.17	.92	-40.713	-37.332	40	Direction of Flight Angle 12 Back
Flight α 6	-40.13	1.17	-42.675	-38.056	40	Flight Direction Angle 6 Back
$Velocity_H$ 12	21.62	.78	19.963	23.953	40	Horizontal Velocity 12 Back
$Velocity_H$ 6	21.63	.82	19.920	23.265	40	Horizontal Velocity 6 Back
Knee α_{XY} 12	111.57	11.96	93.238	136.340	40	Right Knee Angle 12 Back
Knee α_{XY} 6	112.48	11.66	81.140	135.10	40	Right Knee Angle 6 Back
Legs α_{XZ} 12	11.39	8.82	-3.209	30.011	40	Leg and Leg Angle 12 Back
Legs α_{XZ} 6	16.68	15.40	-14.76	64.854	40	Leg and Leg Angle 6 Back
Arm α_{XZ} 12	55.17	27.74	21.206	139.643	40	Right Arm Angle 12 Back
Arm α_{XZ} 6	88.49	140.56	21.428	939.000	40	Right Arm Angle 6 Back
Ski/Leg α_{XY} 12	39.12	8.71	22.495	61.976	40	Ski and Leg Angle 12 Back
Ski/Leg α_{XY} 6	49.18	10.76	20.563	71.732	40	Ski and Leg Angle 6 Back
Ski V α_{XZ} 12	9.77	5.56	-.355	24.233	40	Ski and Ski Angle 12 Back
Ski V α_{XZ} 6	6.31	4.57	-5.816	13.008	40	Ski and Ski Angle 6 Back
Ski/Trunk α_{XY} 12	32.35	8.46	9.434	45.590	40	Ski and Trunk Angle 12 Back
Ski/Trunk α_{XY} 6	38.04	10.24	15.937	57.723	40	Ski and Trunk Angle 6 Back
Trunk/Thigh α_{XY} 12	124.12	14.68	79.177	149.314	40	Trunk and Thigh Angle 12 Back
Trunk/Thigh α_{XY} 6	101.34	15.82	55.642	134.416	40	Trunk and Thigh Angle 6 Back
$Velocity_V$ 12	-17.62	.72	-19.135	-16.200	40	Vertical Velocity 12 Back
$Velocity_V$ 6	-18.24	.70	-19.888	-16.866	40	Vertical Velocity 6 Back

Table 18

Mean Performance Measures

Preparation For Landing Analysis For All Variables (N=21)

Variable	Mean	Std Dev	Min.	Max.	N	Label
Δ $Velocity_H$	.57	.95	-.875	2.532	21	Change In Horizontal Vel. 12 - land
DISTANCE	73.43	2.37	70.0	78.5	21	Distance Jumped
Flight α 12	39.60	.78	38.216	40.713	21	Direction of Flight Angle 12 Back
Flight α 6	40.56	1.13	38.444	42.675	21	Flight Direction Angle 6 Back
$Velocity_H$ 12	21.84	.80	20.514	23.953	21	Horizontal Velocity 12 Back
$Velocity_H$ 6	21.71	.73	20.375	22.935	21	Horizontal Velocity 6 Back
Knee α_{XY} 12	131.34	10.29	117.411	154.222	21	Right Knee Angle 12 Back
Knee α_{XY} 6	114.02	12.27	93.4469	135.108	21	Right Knee Angle 6 Back
Legs α_{XZ} 12	10.65	9.57	-3.209	30.011	21	Leg and Leg Angle 12 Back
Legs α_{XZ} 6	16.76	18.82	-14.764	64.854	21	Leg and Leg Angle 6 Back
Arm α_{XZ} 12	52.30	22.86	23.460	118.074	21	Right Arm Angle 12 Back
Arm α_{XZ} 6	109.42	33.36	29.561	139.000	21	Right Arm Angle 6 Back
Ski/Leg α_{XY} 12	39.25	9.63	26.072	61.976	21	Ski and Leg Angle 12 Back
Ski/Leg α_{XY} 6	50.78	12.20	20.563	71.732	21	Ski and Leg Angle 6 Back
Ski V α_{XZ} 12	9.51	6.37	-.355	24.233	21	Ski and Ski Angle 12 Back
Ski V α_{XZ} 6	5.90	4.86	-5.447	13.008	21	Ski and Ski Angle 6 Back
Ski/Trunk α_{XY} 12	35.23	8.66	9.434	45.590	21	Ski and Trunk Angle 12 Back
Ski/Trunk α_{XY} 6	42.39	9.62	18.439	57.723	21	Ski and Trunk Angle 6 Back
Trunk/Thigh α_{XY} 12	127.32	11.60	107.510	149.314	21	Trunk and Thigh Angle 12 Back
Trunk/Thigh α_{XY} 6	105.64	12.36	85.280	134.416	21	Trunk and Thigh Angle 6 Back
Displ. C/M 12	4.13	.13	3.924	4.310	21	Vertical Displacement 12 Back
Displ. C/M 6	2.29	.11	2.117	2.481	21	Vertical Displacement 6 Back
$Velocity_V$ 12	-18.06	.50	-19.135	-17.080	21	Vertical Velocity 12 Back
$Velocity_V$ 6	-18.58	.63	-19.888	-17.678	21	Vertical Velocity 6 Back