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THE DEVELOPMENT & SOCIETAL IMPACTS OF A SPEED MODEL FOR TERRAIN PARK JUMPS

An Interactive Qualifying Project Report
submitted to the Faculty
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By

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Date:

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1. Safety Analysis & Liability

ABSTRACT

The objective of this project was to develop ways to design safer terrain parks. Two separate models, The Geometrical Jump Design Model and The Speed Model, were developed and produced criteria for the initial design and predicted the speed for any jump. To understand the opinions of society on terrain park safety and this research, questionnaires were distributed within the skiing culture. Through field data and surveys it was found that utilizing terrain park design models and integrating them into society and terrain would mostly be welcomed and used.

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1 INTRODUCTION

The integration of park & pipes into the snowsports industry has come fast and with little guidelines or instructions. Over the past 15 years, according to National Ski Areas Association (NSAA 2003) there has been an increased amount of terrain parks added to ski areas in the United States. The first known on snow Terrain Park was founded at Big Bear Resort in California in 1991. As of 2004, 243 of the 340 NSAA ski resorts had terrain parks, halfpipes, or both. The industry average for injury rates is higher in terrain parks than on other downhill areas of ski resorts due to the fact that most skiers and snowboarders are hitting jumps, riding rails, and/or the halfpipe and thus the risk for injury is naturally higher. The increased popularity of terrain parks has attracted more and more skiers and snowboarders every year and in the 2003/2004 season there was almost an even amount of boarders and skiers entering parks [1].

The increasing popularity of terrain parks and the increased ability levels of skiers and snowboarders helped push resorts to start basic safety procedures & protocol in terrain parks. Resorts set safety protocol and standards by producing safety signage about terrain parks, creating more awareness in terrain parks through videos & offering ski classes, and requiring mandatory terrain park passes to permit skiers and snowboarders into terrain parks. Not all ski resorts incorporated these safety procedures at their mountain but over the years there has been an increase in promoting safety, awareness, and learning about terrain parks [1].

One of the first organizations to address the issue regarding safety in terrain parks was the National Ski Areas Association (NSAA). NSAA partnered with Burton and started a program called “Smart Style” which provides information and signage for

Terrain Parks, freestyle, and pipe features. In order to be able to provide education to the public about freestyle related maneuvers, obstacles, and skills the Professional Ski Instructors of America (PSIA) has developed a Freestyle Teaching Curriculum Task Force that are qualified to teach and prepare instructors in the different freestyle techniques and safety concerns [1].

Even though there have been safety precautions and awareness programs administered by ski areas and parks there currently exists no standards or scientific analysis by which terrain parks are built, designed, managed, and operated. There also is little to no research related to the scientific analysis, standards, or designing of Terrain Parks. Developing and researching these things are not difficult tasks because similar international sports like Freestyle Skiing and Nordic Jumping have design standards and governing bodies which control and set standards as related to design, operation, and management of jumps.

In order to address these issues this project investigated how to design terrain park jumps, develop scientific standards, and looked at the law and societal issues that are related to Terrain Parks. A speed model was developed to produce a recommended speed for terrain park jumps to be used to build, operate, and maintain a safer park. A variety of questionnaires to different parties were also distributed in order to understand the current status of terrain parks and the perceived societal impacts of the speed model. It is not the obstacle of designing for safe terrain parks that needs to be overcome, but it is the law and societal issues related to Terrain Parks which affect the application of this research and need to be overcome in order to reap the benefits of using this technology in Terrain Parks. Successful integration of this model into terrain parks could mostly remove the worry of undershooting or overshooting the landing of any jump, reduce speed related injuries, and create safer terrain parks.

1.1 Rationale

Skiers and snowboarders from the general public, local competition scenes, and elite international competition scene, whether at a small recreational mountain, a world renowned terrain park, international freeride competition, or in the backcountry are injured or even die every year from jumping related injuries. According to a study prepared by Jasper Shealy of Rochester Institute of Technology in 2003, the injuries of snowboarders that result from jumping are 18% where the injuries resulting from jumping for skiers is nearly three times less at only 7%. Even with the increased popularity of parks the catastrophe rate for snowboarding has remained steady over the past 10 years. If there were more safety standards and specific design concerns taken by park managers, ski area management, ski patrol, and event coordinators the injury statistics could possibly be even less than they are currently [1]. Therefore how a mountain organizes their Terrain Park Staff, how the staff designs the park, and the law and societal issues related to Terrain Parks all affect how to design a safe Terrain Park.

Most Terrain Parks are built by mountain staffs who are employed for management, maintenance, and operation of the Terrain Park. These parks are built on the park's management's experience, trial and error, and forecasting of what the riders like and dislike. Some mountains enlist help designing, building, and maintaining their park from terrain park design companies like Snow Park Technologies, SnowPark Management Unlimited, and Premium Terrain Park Design. These companies are composed of some of the most innovative and experienced freestyle park and pipe innovators that provide design, consultation, maintenance, and operation services to mountains worldwide. How Terrain Parks are designed, built, and operated is only a part of investigating how to make Terrain Parks safer. There exist other law and societal issues like liability and statutes which also affects Terrain Parks, related research, and setting scientific standards.

Out of the popularity and increase in injuries resorts looked to make Terrain Parks safer. Some of the ways that mountains have tried to create safer terrain parks is through safety, education, and awareness. Over the last five years these issues have been widely addressed and resulted in the creation of such programs as the Burton & NSAA Smart Style Program, safety awareness terrain park programs run by mountains, and education programs promoted by the Professional Ski Instructors of America (PSIA).

The design of Terrain Parks has not been approached nearly as aggressively as safety and awareness has. Some companies have risen out of the new popularity of terrain parks and these companies have professionals whose specialties are designing terrain parks and then implementing the design at ski areas. Although most ski areas do not use these companies to build their terrain parks they use their own staff hired by the ski area to design and operate the terrain park. Some mountains require certain educational requirements for park staff but a variety of mountains do not. If it were possible for park managers and designers to have a program or design protocol which they could create their parks from the amount of bad designed parks would sufficiently decrease as a result, thus efficient park design is a large societal concern.

Another issue that is of major concern to ski area operators is liability. With the increased amount of guests entering terrain parks, even with the skier's responsibility code, ski area’s have a greater liability and risk because of parks. Any measure that a ski area can take that will help to reduce its insurance policy, liability, or risk is usually done. There has been great progress in injury prevention with the intervention of terrain park safety awareness programs which has helped reduce liability, risk, and insurance concerns, but what if there could be more done which would reduce injuries and increase safety in terrain parks even more? If it could benefit both guests entering terrain parks and ski areas together, it is possible that it would be of great concern of ski area managers and operators around the world in addition to other parts of the skiing community like ski patrollers, freeride competitors, public skiers and snowboarders, park management & crew, and insurance companies.

Ski area management, freeride competition/event coordinators, park managers & crew, competitive freestyle skiers and snowboarders, new terrain park users, recreational skiers, insurance companies, and snowsports safety researchers all could utilize and be affected by the results of Terrain Park research. Freeride event coordinators along with park managers could use this research to create more controlled and properly designed courses and terrain parks, competitive riders could use the information to help them be more accurate and productive with their jumping, recreational skiers could use the information to provide more comfort to get themselves progressing and involved in terrain parks safely, and both ski area management and insurance companies could use the information to help reduce injury statistics at their area and thus reduce their insurance premiums, and researchers could use this research as a basis by which further research in the field of terrain park study and design could be analyzed. Despite these attempts at making Terrain Parks safer the injury rate in Terrain Parks is still higher than any other area on the mountain, serious injuries still exist, and Terrain Parks are still being designed wrong, unsafe, and bad.

1.2 State of the Art

Terrain Parks are a new area of research and there exists almost no research related to designing and analyzing Terrain Parks, developing scientific standards, or developing a speed model for Terrain Park jumps. Dr. Jasper Shealy is one of the few has performed research related to Terrain Parks. He is a renowned researcher in the field of ski related injuries and is a retired professor from Rochester Institute of Technology. His research analyzed the trajectory and landings of terrain park jumps. A full overview of his research is presented in the background section of this paper under Terrain Park Research. In May 2007 in Aviemore Scotland, the International Society of Skiing Safety Conference is going to take place and four different presentations related to Terrain Parks are scheduled, one of which is this research.

1.3 Objective

The objective of this project was to look at ways to make terrain park jumps safer. This involved looking at how Terrain Parks are designed, built, and operated, looking at how mountains staff & educate their Terrain Parks, and the way that law and society govern Terrain Parks. Based on an earlier project conducted in The Technology of Alpine Skiing Class administered by Professor Chris Brown at Worcester Polytechnic Institute, it was found that the best way to develop a way to make terrain parks safer was to look at how terrain park jumps were designed. The major technological concerns of this project consist of the design of terrain parks, the procedures and analysis that are considered upon the construction of terrain parks, and the law and societal issues related to Terrain

Parks. Even though safety programs have proven to reduce Terrain Park related injuries, there still exist injuries that result from jumping. Being able to provide engineered logic on terrain park design and then incorporate it into daily maintenance and operation of terrain parks could provide even better reduced injury statistics and make Terrain Park jumping safer for everyone.

The results from this project will be derived from a speed model that was created to produce speed requirements to reach the jump landing safely. The research was conducted by gathering information from three separate mountains across the United States Breckenridge, Copper Mountain, Sunday River, and then input into the speed model. The results from the data collection and speed model will be presented in tables, graphs, and case comparisons. In order to develop and understand the law and societal issues surrounding Terrain Parks, interviews and surveys were conducted asking questions related to this project's research, safety, education, and their mountain's Terrain Park protocol from various parties. These results will be presented in percentages, majority and minority, stated opinions, and general observations.

However, even though there is little research available in the field of Terrain Park Skiing, related sports like Nordic Ski Jumping and Freestyle Inverted Aerials provide adamant research and information that is similar in nature. An overview of these sports and the correlating research will be provided before an overview of Terrain Parks and the corresponding research is presented. Then an understanding of where Terrain Parks stand in terms of safety, law, and society will be provided to be followed by the resources and methods of which this research was conducted. Lastly, the speed model and related data will be presented, analyzed, and then conclusions will be made along with future recommendations for research in this area.

2 BACKGROUND

Terrain Parks are similar to two other sports related to jumping Nordic Ski Jumping and Freestyle Inverted Aerials. All three of these sports encompass skiers approaching a jump, riding off of it, and then landing. These sports differ however in the equipment they use, their takeoff position and maneuver, how they perform in the air, and how they land. Unlike Terrain Parks, Freestyle Skiing and Nordic Ski Jumping have been around longer and have design standards, specifications, and their jumps are not usually open to the public unless supervised and coached by a professional. Thus research from Nordic jumping and freestyle inverted aerials can be used as a basis to understand the physics of jumping.

Even though each sport is different from one another they all are related by the mechanics and physics of jumping. Nordic Jumping jumps are flat and long and they have long gradually steep landings whereas Freestyle Inverted Aerial jumps have short in length and tall in height and steep landings. Understanding how both these sports developed their standards and utilize them to design jumps provides great insight into how Terrain Park jumps could be designed. Research on Nordic jumps and landing hills, physics of freestyle inverted aerials, and a recent presentation regarding jumping techniques in terrain parks provides important information to aid the research and development of the speed model.

2.1 Nordic Ski Jumping

Nordic Ski Jumping is a sport where skiers try to jump of fly as far as possible smoothly. Ski Jumping was found in Norway by Sondra Norheim who jumped 30 meters on skis without ski poles over a rock. Two years later the first ski jumping competition was held in Trysil, Norway. As ski jumping developed the techniques and design of jumping hills also did. The Kongsberger technique was developed by Thulin Thams and Sigmund Rudd after World War I and changed the body stance of ski jumpers from the earlier style to a style of jumping with the hips over the skis, arms extended behind, and a more forward lean, as seen below. From the new techniques skiers could now reach farther distances down the hill, so ski jumping hills were designed to the contour of the path of the jumpers to where at no time they would be more than 20 feet off the ground.

Figure 2-1: Old Ski Jumping Technique v. Kongsberger Technique

2.1.1 Ski Jumping Hill & Competition Specifications

Ski jumping competitions are organized in the United States by the United States Ski Association and internationally by the International Federation of Skiing (FIS). The standards for construction of jumping hills can be seen in the Appendix. As the jumping technique and equipment develop the biomechanics of ski jumping also change and develop. There have been various kinds of research on different factors of ski jumping but what is related to Terrain Park jumps the research pertaining to the jumping hill design of Nordic Ski jumping hills.

2.1.2 Ski Jumping Research

W Muller in Science and Skiing presented research on the biomechanics of ski jumping – scientific jumping hill design where he analyzed the current design of jumping hills and how there needs to be new changes made to the regulations for new jumping hill designs. The flight phase of a Nordic jumping is highly affected by the aerodynamics of the ski jumper and enforcing regulations to reduce the increase of aerodynamics of the jumper is essential. Besides that fact, Muller contends that the results from his analysis of ski jumper's paths and the profiles of modern ski jumping hill designs will provide a basis for modern ski jumping hill design [12].

In his analysis he looked at the different flight paths and their associated approach variables, the dependency of landing height on jump length, and the dependency of landing height on various jump lengths. What he found was that the landing height at a given jump length depends on the different parameters and initial values that were used. In order to redesign an old hill or create a modern one based of his research there would need to be an extensive analysis of existing hills and a large set of protocols for creating a modern hill because additional extreme conditions would need to be considered in order to maximize both the safety and attractiveness of ski jumping competitions [12]. It can be seen that analyzing a variety of parameters in relation to jump height, jump length, and incoming velocity are all important factors to consider in optimizing the safety of Nordic ski jumping hills.

2.2 Freestyle Inverted Aerials

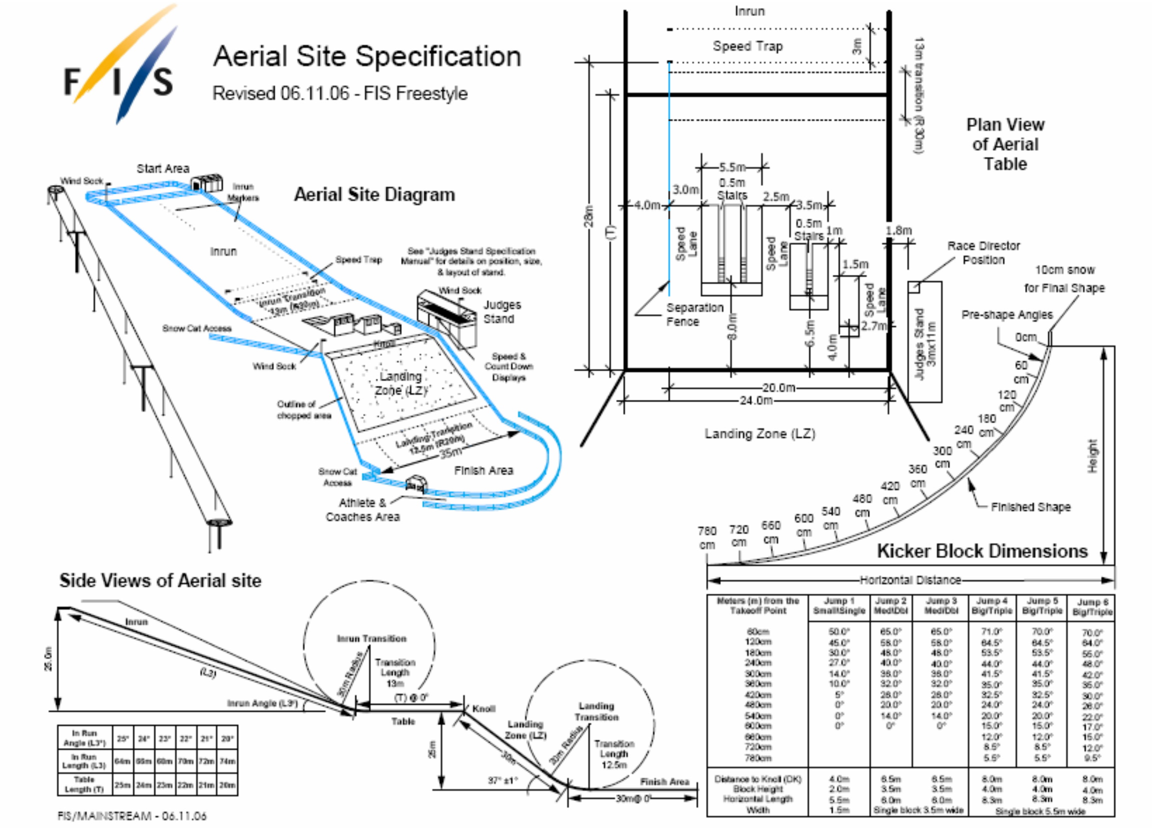
Inverted Aerials is an alpine skiing sport where skiers perform inverted maneuvers off jumps on snow. The first measured inverted maneuver was from a Norwegian in 1860. The sport was called Hot Dog Skiing in the 1960's before the official name of Freestyle Skiing was set. The sport's roots go back to when Stein Eriksen, a 1952 Olympic gold and silver Medalist in ski racing, would perform somersaults for audiences off snow jumps. One of the first hot dog competitions was in Alta, Utah. Three years later due to serious injuries resulting from more daring and dangerous maneuvers by competitors inverted aerials were banned from competition and delayed the addition of hot dog skiing being brought to the World Cup level of competition [7].

Figure 2-2: Freestyle Inverted Aerial Maneuver

In 1980 the first World Cup event for Freestyle Skiing was held. In 1986 the first World Championships were held including ballet, moguls, and inverted aerials. Then in 1988 Freestyle Skiing was a demonstration even at the Calgary Olympics, which roared and amazed crowds. The next Olympics in 1994 at Lillehammer, Norway Freestyle Skiing was a medal event [7].

2.2.1 *Inverted Aerials Site & Specifications*

Since Freestyle Skiing became a World recognized sport, at World Cup and Olympic levels, there were rules that were required for the courses which skiers competed on. Also the high amount of serious injuries incurred in the early years of the sport also pushed for standardizations for the sport. World Cup Events are governed and run by the International Ski Federation, and rules and Specifications for Freestyle Competitions were developed through this organization.



In Run Angle (L3°)	25°	24°	23°	22°	21°	20°
In Run Length (L3)	64m	66m	68m	70m	72m	74m
Table Length (T)	25m	24m	23m	22m	21m	20m

Meters (m) from the Takeoff Point	Jump 1 Small/Single	Jump 2 Med/Dbl	Jump 3 Med/Dbl	Jump 4 Big/Triple	Jump 5 Big/Triple	Jump 6 Big/Triple
60cm	50.0°	65.0°	65.0°	71.0°	70.0°	70.0°
120cm	45.0°	58.0°	58.0°	64.5°	64.5°	64.0°
180cm	30.0°	48.0°	48.0°	53.5°	53.5°	56.0°
240cm	27.0°	40.0°	40.0°	44.0°	44.0°	48.0°
300cm	14.0°	38.0°	38.0°	41.5°	41.5°	42.0°
360cm	10.0°	32.0°	32.0°	35.0°	35.0°	36.0°
420cm	5°	28.0°	28.0°	32.5°	32.5°	30.0°
480cm	0°	20.0°	20.0°	24.0°	24.0°	26.0°
540cm	0°	14.0°	14.0°	20.0°	20.0°	22.0°
600cm	0°	0°	0°	15.0°	15.0°	17.0°
660cm				12.0°	12.0°	15.0°
720cm				8.5°	8.5°	12.0°
780cm				5.5°	5.5°	9.5°
Distance to Knoll (DK) Block Height Horizontal Length Width	4.0m 2.0m 5.5m 1.5m	6.5m 3.5m 6.0m Single block 3.5m wide	6.5m 3.5m 6.0m	8.0m 4.0m 8.3m Single block 5.5m wide	8.0m 4.0m 8.3m	8.0m 4.0m 8.3m

Figure 2-3: Aerial Site Specifications

Figure 2-3: Aerial Site Specifications shows the current Aerial Site Specifications for FIS sanctioned freestyle competitions. All world cup freestyle aerial events are supposed to be built and run according to these specifications. Notice that a key feature to their aerial site design is designating the location of where the speed trap is located. Also they provide a highly detailed Kicker (also known as a jump) block dimensions for the different variation of jumps that are used.

Unlike FIS, the United States Ski & Snowboard Association (USSA) which is the governing body for skiing in America has specifications and rules of its own, but unlike FIS, USSA rules are less detailed. These specifications and guidelines noted in the Appendix are used for courses because they provide a universal guide for all ski areas and event organizers of how to build a course.

2.2.2 Freestyle Inverted Aerials Research

There exists little research on the analysis of trajectories and landings for Freestyle Inverted Aerials. One paper by Donald P Wylie at the Space and Science and Engineering Center at the University of Wisconsin-Madison, compares the landing force of Freestyle Inverted Aerialists to Nordic Ski Jumpers. The model that Wylie uses for his results comes from a Nordic jumping model developed by Muller [8]. The trajectory of a freestyle aerial jumper is higher and shorter than that of a Nordic jumper. Aerialists are scored on height, difficulty, & performance, but are not scored on distance like Nordic jumpers [9].

The force that an aerialist incurs is not the vertical distance that the skier drops from the height of their jump to the landing hill because they land on a slope of about 37º and they do not stop once they land, they continue skiing down the landing hill. The force that is felt by the skier when he/she lands is the change in direction from the skier dropping vertically from their flight to skiing down the slope of the landing hill. A diagram demonstrating this concept is seen in Figure 2-4: Aerialist Landing Force Diagram. The skier's velocity approaching landing is denoted $V_{A\text{-}B}$, which can be expressed as two orthogonal components, $V_{A\text{-}C}$ and $V_{C\text{-}B}$. Vector $_{A\text{-}C}$ is the component along the hill whereas vector $_{C\text{-}B}$ is the other. When the skier lands, the change in direction is seen by the angle ***a*** and his/her velocity will change from $V_{A\text{-}B}$ to $V_{A\text{-}C}$, as $V_{C\text{-}B}$ is absorbed in the landing impact of the skier. Thus the force of impact that the skier experiences upon landing is the absorption of force $V_{C\text{-}B}$ [9].

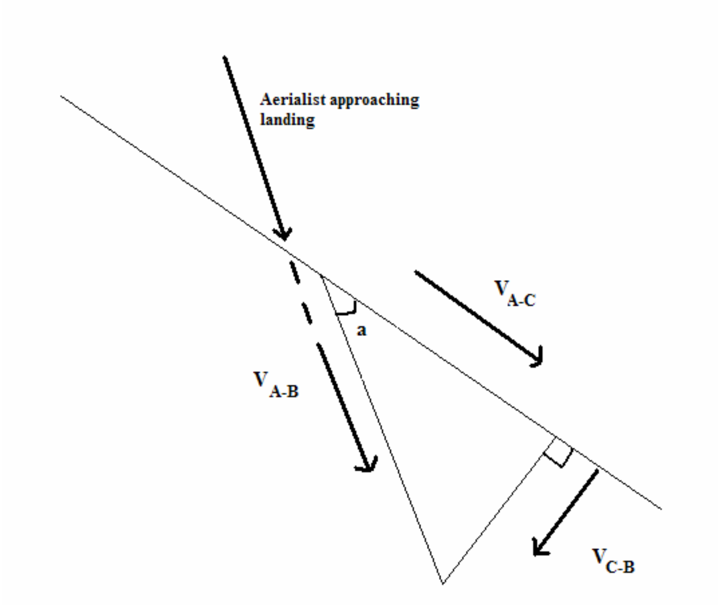


Figure 2-4: Aerialist Landing Force Diagram

Using Figure 2-4: Aerialist Landing Force Diagram, it can be seen that the aerialists velocity component is perpendicular to the landing hill, $V_{C\text{-}B}$, and thus it can be found by the aerialist's velocity, $V_{A\text{-}B}$ and the change of direction noted by angle *a*. The resulting Equation is:

$$V_{C-B} = V_{A-B} * SIN(a)$$

Equation 2-1: Velocity Component Equation

The trajectory model takes a series of small time steps (.05 seconds) and calculates the skier's velocity and position at each step as seen in Figure 2-5: Flight Trajectory Model Visualization below. The non-orthogonal green arrows show the different velocities at each time step, the orthogonal black arrows indicate the velocity and distance component vectors for the skier's trajectory.

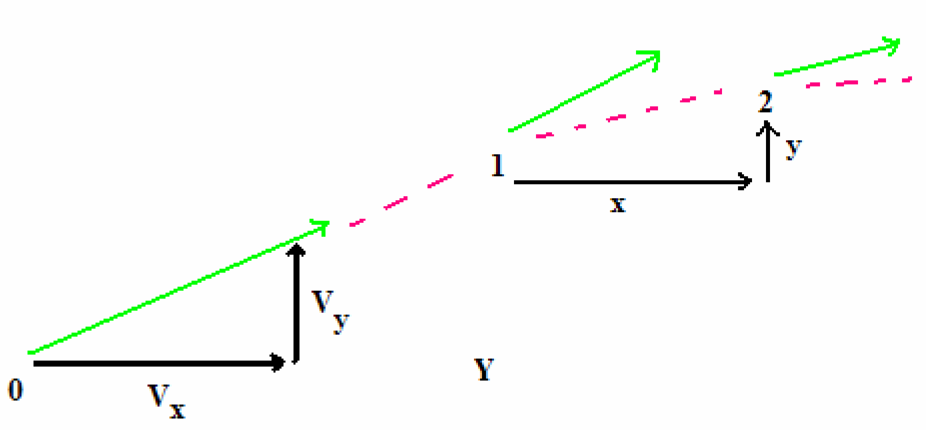


Figure 2-5: Flight Trajectory Model Visualization

The model works by using the takeoff speed and direction and for each time increment calculates how far the skier moves. Wylie uses .05sec time increments which results in about a .05 meter displacement per increment. Since new forces act of the skier for every time step a new velocity is calculated each time. A new position is then calculated using the average velocity of the time increment which is then followed by a re-calculation of the skier's velocity. This process is done anywhere from 60-100 times until the skier reaches the landing, which varies depending on the size of the jump and length of trajectory [9].

The skier's trajectory vector (indicated by the green arrows) is broken down into an x-component (horizontal) and a y-component (vertical) for easier calculation. The x component always increases in the positive x direction and the y component increases upward and then downward after optimal height of trajectory is reached. The skier's position at the end of each time step is indicated below:

$$X_2 = X_1 + 0.05 \times V_X$$

Equation 2-2: X-Component Position Equation

$$Y_2 = Y_1 + 0.05 \times (V_{y1} + V_{y2}) / 2$$

Equation 2-3: Y-Component Position Equation

The subscripts in the equation indicate the start and end of a time step, 1 is the start and 2 is the end. The velocities that act on the skier differ by the accelerations of the forces on the skier. The speed that the aerial skier incurs is relatively lower than that of a Nordic skier; aerodynamic lift and drag are not considered. When velocities in the range of 23-27 m/s or 51-53 mph that is when aerodynamic factors need to be considered. It is assumed that the horizontal velocity component (V_x) is constant in relation to time and that the only acceleration on the vertical velocity component (V_y) comes from gravity. Thus the equations that are used to calculate the velocity components for the aerialists are:

$$V_{x2} = V_{x1}$$

Equation 2-4: Horizontal Velocity Component

$$V_{y2} = V_{y1} - G \times 0.05$$

Equation 2-5: Vertical Velocity Component

The model works by taking the velocities at the takeoff which are V_{x0} and $_{Vy0}$ and then calculates $_{Vx1}$ and $_{Vy1}$ using the velocity component equations. Then x_0 and y_0 are the initial starting position (takeoff) and then x_1 and y_1 are calculated using the Position Equations indicated above. Then V_{x2}, V_{y2}, x_2, and y_2 are calculated and so on [9].

The data that we have for the aerialist version of the model is the location of the takeoff point and the takeoff angle, but the velocity of the aerialist is not known. Jumpers choose their velocity based on their jump and degree of difficulty. Although the jumper's velocity can be estimated by assuming that the aerialist wants to land in a safe area on the landing hill. By choosing the farthest that a jumper could land down the landing hill safely the maximum air time is used [9].

In order to compute this, a reverse iterative method is used to find the takeoff velocity from the point of estimated landing. An estimated velocity is used to determine an estimated point of landing. If the model produces a landing too short or too long with the estimated velocity, the velocity needs to be increased or decreased to find the desired landing point and corresponding velocity. The takeoff velocity can usually be found within a few tries; commonly less than ten says Wylie [9].

Wylie took specifications from the FIS aerial site specifications to run an example through the model. He considered the largest jump which has an inclination of 55° and is position 8.1 meters back from the landing hill, which has a consistent pitch of 37 ° and is 25 meters long. After consecutive runs of the model Wylie found out that at a takeoff velocity of 12.5 m/s@ (28 mph) would put the aerialist 26 meters from the jump and 10 meters from the bottom of the landing hill. The skier's airtime is 3.0 seconds and the aerialist's height was 5.5 m (18ft.) above the takeoff. The skier dropped 18.7 meters (64 ft) from the apex of the jump to landing on the hill. The skier's velocity when landing was 20.5 m/s (45mph) at a declination of 69 ° when landing. The impact velocity, V_{C-B} is 11 m/s [9].

In order to enable for comparisons to other sports (Muller, 73) the vector VC-B was converted to an equivalent drop from a given height to a flat surface. Through use of the basic equations for acceleration and distance in a gravitational field the conversion was derived.

$$H = 0.5 \times V_{C-B^2} / G$$

Equation 2-6: Impact Velocity Conversion

Using this equation the impact velocity of the above example is converted to an equivalent vertical drop of 6.1 meters (20ft). A table providing all the results from the model example is provided below.

Takeoff Angle	Velocity	Jump Distance	Total Vertical Fall Distance (meters)	Landing VA-B	Landing VC-B	Equivalent Drop to Flat Surface	Flight Time
Deg	m/s, mph	Meters, (feet)	Meters, (feet)	m/s	m/s	Meters, (feet)	
55	9.7 (21.3(	15 (49)	10 (33)	15.1	7.9	3.2 (10)	2.2
55	12.5 (27.5)	26 (85)	19 (62)	20.5	11.0	6.1 (20)	3.0

Table 2-1: Aerial Jump Model Run Parameters

2.3 Newschool Skiing and Terrain Parks

Freeride skiing is a type of skiing which involves advanced tricks, jumps, and terrain park features, such as rails. This form of skiing is considered a combination of the growth in popularity of snowboarding as well as the progression of Freestyle skiing. "Newschoolers” or those who specifically ski in this style (as opposed to freestylers, big mountain, racers, etc.) are often found in terrain parks, which are designed specifically for hitting jumps and performing tricks.

In the late 1990’s FIS had placed more strict restrictions and laws placed on the sport of freestyle skiing which began to limit the progression of the sport. Laws like banning inverted tricks in competitions, limiting the number of flips allowed in aerial competitions, and not supporting a more free atmosphere in freestyle skiing helped ‘freeride’ or ‘newschool’ skiing to arise. The term newschool came from the coined FIS term of freestyle skiing and referred to a new type and modernized form of freestyle skiing. The newschool skiers were hitting the terrain parks which were at that time prominently snowboard dominated and developing a new updated version of freestyle skiing. Attentive to the snowboarder’s style and culture, newschool skiers developed their own form of style for their own sport along with new tricks, silly names, and an entirely new form in skiing culture.

As the sport progressed so did the amount of skiers entering terrain parks and the need for safer and better designed terrain parks. Mountains have tried to address the safety issues by designing safer jumps, hiring terrain park designers, and conducting safety clinics before letting the public into the terrain park. Most of these measures have provided some amount of relief related to the issue of safety but many skiers are still being hurt because of ill designed jumps and/or landing hills.

Unlike Nordic Jumping and Freestyle Skiing, skiers that perform newschool tricks can be anyone; there are no skiing jump qualifications, professionals to monitor them, or other requirements. There is an extremely more accessible are than the other two sports which have standards, yet Terrain Parks do not have any set standards when it comes to designing and implementing jumps. There are also no professional standards required in order to design and/or operate and maintain Terrain Parks.

2.3.1 USSA Terrain Park Specifications

The United States Ski Association has recently hosted slopestyle and big air jumps and has created broad standards upon which the competition hills need to be built upon. These standards however hold only for USSA competitions and have not been applied to public terrain parks. For an overview of USSA Slopestyle and Big Air specifications See Appendix A & C. USSA has also integrated Slopestyle and Big Air seminars into their Freestyle Skiing Coaching clinics.

Since the sport is new and because of the demographic of its culture there have been little to no efforts to understanding how to design terrain park jumps. Just as Nordic ski jumping and freestyle inverted aerials developed rules over the life of the sport, Terrain Parks hopefully will evolve similarly but still not be as restricted a sport as Nordic and freestyle are.

2.3.2 Terrain Park Research

In July of 2007, Jasper Shealy, a renowned researcher in ski related injuries, presented research at an American Society for Testing & Materials Conference on Terrain Park Jump Trajectory Analysis and Jump Landing Analysis. On a jump, the skier/snowboarder's trajectory is determined by the jumper's input on subsequent trajectory and the force that the jumper encounters on landing is their body's ability to absorb shock [10].

Shealy noted that human input is the contributing factor that determines the trajectory of a rider on the jump. There are a variety of factors that a jumper needs to react to which together affect their trajectory. These factors include angle of take off, speed at moment of flight, action of jumper on the lip of the jump, i.e.: pre-jump, pop, or buckle. All these factors affect the jumper's trajectory, but to compute the trajectory of the jump all that is needed is the angle of departure from the jump and the speed at point of departure. This can be determined using Classic Newtonian Ballistic Physics. A general assumption of the jumper is that he/she is like a cannon ball being shot, in that no action in the air actually affects the trajectory of the jumper [10].

Although a jumper's actions prior to leaving the jump DO affect the trajectory. The ideal action of a jumper upon takeoff is when a jumper *pops*. If this occurs at takeoff, then the kinetic energy is affected and it increases the angle of takeoff for the jumper. Thus the kinetic energy created by this action is just added to the vertical component of the jumper's takeoff velocity [10].

Another takeoff action performed by a jumper is a *pre-jump*. When a jumper pre-jumps he/she reduces the angle of takeoff by taking off prior to the end of the jump. The jumper still holds forward velocity on the jump but because the angle was reduced the jumper will get less air than if the jumper were to perform a *pop* action [10].

The last takeoff action that a jumper can perform is to *buckle* or absorb the takeoff. When a jumper absorbs the takeoff he/she effectively reduces the purpose of the takeoff of the jump and loses a large amount of possibility of completing the jump, which can be very dangerous. [10].

Because of the different types of takeoff maneuvers possible for jumpers it can be seen that predicting the performance of a jumper on a terrain park jump requires more than just the jump angle and takeoff speed. The effect that a human's input has on their trajectory is quite large and can even add or subtract from 15° to 30° from the takeoff angle [10].

2.4 Law, Society, & Terrain Parks

Understanding how law and society relates to Terrain Parks is important to understanding why terrain parks are currently not designed according to standards or specifications. Terrain Parks are unlike any other area on the mountain because they are man made obstacles that are intended for skiers and snowboarders to hit and get air. What causes many lawsuits and issues is the associated liability with such disasters. On every ski ticket whether a day, week, or seasons pass there is a skier code and responsibility which essentially waives the ski resort from being liable for anything that the skier or snowboarder does while riding at the mountain. What happens when an injury results from a skier or snowboarder hitting an obstacle which the mountain created, designed, operated, and maintained? Is the skier, snowboarder, or ski resort liable for the injury or death? Answers to these questions vary from state, judge, and jury and how they are answered can have a large affect on how ski resorts manage, design, and operate their Terrain Parks.

2.4.1 The Law

In 2003 at Washington State’s Summit at Snoqualmie ski area, Kenny Salvini now 27, flew off a jump in the terrain park and broke his back on the hard-packed snow, leaving him paralyzed. In April of 2007 a jury in Kent, Washington awarded hi $14 million which marked the largest award by a jury against a US ski resort. Jim Chalat a Denver attorney who specializes in ski law also stated that:

> "The repercussions will probably be that terrain parks will be constructed more carefully, and that's a good thing," "I would hope that more attention is paid to the proportionate elements so that a jump isn't by design launching riders over the

> landing area. Liability breeds responsibility. Immunity breeds impunity to safety considerations." [13]

What is most ironic about this situation is that Booth Creek, a ski holding firm, who owns Snoqualmie, also owns and operates Snow Park Technologies (SPT), a leading firm in designing and constructing Terrain Parks. SPT has built world class event courses like the ESPN X-Games and the firm is also in charge of designing the Terrain Parks for all six of Booth Creek's ski resorts. From situations like the one stated above many states are changing their state statutes related to skiing to incorporate freestyle skiing and terrain parks [13].

Prior to Salvini's fall there had been 15 reported accidents on the jump that season and 10 of them occurred in the 17 days prior to his 37 foot drop to the ground beyond the landing hill. Of those 10 reported accidents in the past 17 days 8 of those injuries resulted in riders being carried down by ski patrol. There had been a variety of incidents including a skier breaking his back the day before and another injury two and half hours prior to Salvini's fall. The terrain park crew over the 15 accidents did nothing to change the jump, which Salvini's attorney argued in court was negligent on part of the mountain. Salvini's attorney brought in different engineers who analyzed the jump and landing and all concluded that the landing was too short for the jump and the takeoff of the jump sent skier to a flat landing. As Salvini's attorney said,

> "As these jumps get bigger and bigger, you need to make sure somebody is looking at those jumps from a civil-engineering or structural-engineering standpoint, just as they do in competitions." "These jumps are not that hard to

> build. It should not take a bunch of people getting paralyzed for resorts to take a close look at safety in their terrain parks." [13]

Under Colorado law, a skier assumes the risk of any injury to person or property resulting from any of the inherent dangers and risks of skiing and may not recover from any ski area operator for any injury resulting from any of the inherent dangers and risks of skiing, including:

* Changing weather conditions

* Existing and changing snow conditions

* Bare spots, rocks, stumps, trees

* Collisions with natural objects, man-made objects, or other skiers

* Variations in terrain

* The failure of skiers to ski within their own abilities.

Despite the Skier Responsibility and Inherent Risk statutes at various states around the country, the Salvini case set a new standard for assigning responsibility for terrain park related injuries. It may possibly as Salvini's attorney said "the impact of the jury's award on the nation's increasingly bigger and burlier terrain parks could change how those parks are designed and maintained." It could be this very case which opens the eyes of ski resorts nation-wide to accepting design standards and technological means towards Terrain Parks [13].

2.4.2 Governing Bodies

USSA does host slopestyle and newschool events nationwide but their events are more geared toward traditional freestyle skiers who are interested in newschool skiing. For the events that occur on weekends, nighttime, or are open events there exists no governing body or association which requires standards or specifications for designing the courses, the mountain and/or event coordinator are responsible for it. Mountains which have Terrain Parks also do not have any specifications or standards upon which to design their parks (as said earlier). Most communication for event registration and advertisement is through magazines and internet.

2.4.3 Society

With the rise of freestyle terrain and terrain parks at mountains many states nationwide have began the process of amending current state statutes regarding liabilities of ski area operators and skiers and ski safety acts. In May of 2004 the Colorado “Ski Safety Act of 1979” was amended to include new sections involving Competition and freestyle terrain and the liabilities of the skier and operator responsibilities concerning that matter. Other states like Ohio and Missouri which don’t have as high of a population of ski areas has also made amendments to their laws involving liability of skiers and ski operators. In cases involving serious or death relation injuries, according to a lawyer interviewed by the Vail Trail, the court has ruled that even if a terrain park feature is built in a “stupid way” or a way in which ordinary physics would launch a rider into the trees, the inherent risk still stands at that of the skier or snowboarder and the resort is not considered liable (according to the state of Colorado statutes). Some mountains like Mt. Baker in Washington have interactive websites which allows the public to view the layout and sometimes the specifications of each feature in the Terrain Park. But, the recent Salvini case might set precedence to change the way that injuries and death in terrain parks are viewed by both society and the law.

3 TERRAIN PARK SAFETY, AWARENESS, & EDUCATION

The most information and research that is available for terrain parks is how safety is approached at mountains, awareness programs, and the education of the individuals who monitor and manage the park. The Smart Style Program developed by Burton along with NSAA, the PSIA Freestyle Terrain Education & Certification, and the Terrain Park Safety & Awareness Programs are the most proactive forms of injury prevention and safety education that are employed by most mountains across the United States. There are no national or state requirements for mountains to hold any awareness programs, present any safety videos, or uphold certain standards in terrain parks, these measures are only recommendations provided to ski areas.

3.1 Smart Style

In 2002 Burton Snowboards and the National Ski Areas Association partnered to create a program promoting safety and educating riders in terrain parks in a clear, precise, yet catchy way. Burton went across the United States to various mountains talking to top park managers, lawyers, and riders to gather information and opinions on terrain park safety. After their surveys and interviews Burton came up with a campaign that provided universal recommended signage and visuals that ski areas could use in their parks to educate riders about park safety and etiquette. They came up with three key safety messages of the Smart Style program: (1) Look Before You Leap, (2) Easy Style It, (3) Respect Gets Respect. Each message relays different aspects of park safety and etiquette.

Figure 3-1: General Sign

In addition to the Smart Style Messages the program also integrated various signage indicating Freestyle Terrain which includes halfpipes, terrain parks and other terrain features. The basic Freestyle Symbol is indicated in the figure below.

Figure 3-2: Freestyle Terrain Sign

There are other signs that were developed as a part of the Smart Style program that promote other safety and park etiquette factors.

Figure 3-3: Halfpipe - Call Your Drop In

The orange circle symbol was integrated into Freestyle Terrain in the 2002 season and since then has become almost as widely recognized as the Green Circle, Blue Square, and Black Diamond terrain difficulty symbols [EXPN.com].

3.2 PSIA Freestyle Terrain Park Education & Certification

The increased need to educate individuals about the new terrain park and pipe field of alpine skiing became another necessity that accompanied the park and pipe movement of the early part of the century. The Professional Ski Instructors of America and the American Association of Snowboard Instructors together developed a curriculum to address the need for a national education and certification program for freestyle park and pipe culture in a period of six months. PSIA and AASI are both non-profit associations that dedicated to promoting snowsports through instruction. Both associations establish certifications for instruction and develop education to be used as the core education for skiing and snowboarding school training. The core of the new developed freestyle terrain curriculum was based on three concepts:

- Create and understanding that the teaching and development of skills in terrain parks is a gradual progression requiring time spent on smaller features,
- Share and reinforce the awareness of etiquette practices and risks involved, and
- Communicate to everyone (riders, instructors, park builders, area management) in a common language.

Resorts have been looking for resources on park instruction and the certification program created by PSIA and AASI has been the first attempt to answer resort's questions (PSIA) [6].

3.3 Terrain Park Safety & Awareness Programs

As the popularity of terrain parks increases along with the size and difficulty of jumps, many resorts are seeking various ways to decrease insurance costs and injuries but still provide guests with a thrilling safe terrain park. The most popular way that ski resorts are achieving these goals are by creating safety and awareness park certification programs (Transworld Business). The safety and awareness programs vary from mountain and mountain but all the mountains aim at providing these types of programs is to promote safety and awareness in terrain parks. Programs consist of watching a video before receiving a pass to being required to pay for a park pass in addition to the lift ticket to be allowed in the terrain park [1].

Stratton Mountain in Vermont led the pack of safety programs in the 2003 season. Stratton has been an integral mountain in promoting and maintaining safety in their terrain park. With the amount of serious injuries the resort had seen prior to 2002, safety and awareness in the terrain park had become a concern among both ski patrol and resort managers. To attack this issue the resort created a terrain park safety program which required guests to obtain a Safety Education Session (SES) pass proving that they had attended a terrain park education session.

As of 2004, for two years in a row Stratton Mountain won the National Ski Areas Association Safety Award for their new program. The program, which is run and was developed by the ski area’s safety and risk manager along with the ski patrol, helped to lower the amount of injuries in their terrain park by 43 percent in 2003 and then by 60 percent in the 2004 season. The program requires all guests (skiers and snowboarders) to attend an education session next to the terrain park which consists of a twelve minute video demonstrating etiquette, safety, and Smart Style awareness. In addition guests receive a brief talk from a trainer or patroller and then are required to sign an Assumption of Risk agreement. The Safety Education Sessions are run every half hour during the day and take about twenty minutes to complete. In 2003 Stratton implemented the program at their high-end terrain park and recorded that over 6000 passes were issued to guests (Ski Patrol Magazine). In 2004 Stratton Mountain implemented their safety program at all five of their terrain parks at the resort and had over 14,000 participants (Transworld Business) [1].

At Breckenridge Resort in Colorado, another type of safety program was created that aims at educating instructors, by issuing Instructor Park and Pipe Credentials. In order to obtain the credentials an instructor needs to attend a clinic and then a verification day where the instructor demonstrates their teaching and riding abilities. After the initial certification the instructor is allowed to take other classes in relation to other parks on the mountain in order to get instruction access to all the other terrain parks. [5]

Figure 3-4 [5]

Breckenridge's David Oliver holds the three color-coded park passes that Breck instructors must have to enter the different levels of parks on the mountain.

Steamboat Mountain in Steamboat Springs, Colorado has also implemented an instructor based clinic that requires instructors to attend a freestyle terrain clinic prior to taking students into parks, pipes, or any freestyle terrain. Aspen/Snowmass Mountain also has a similar program in its third season called the Freestyle Passport program (Transworld Snowboard).

4 METHODOLOGY

After researching various physics equations and concepts a model was developed that output a speed which represented the speed required in order to safely reach the landing hill of a Terrain Park jump. The next step was to go out into the field and collect the necessary information needed to be input into the model. Information was taken from the ski resort's terrain parks, put into tables, and then input into the model. Then the results that the model output were compared, contrasted, and the conclusions for each mountain were obtained. The results showed that the mountain either had well or poor designed terrain park jumps.

Following these results, an analysis of the design of each mountain's Terrain Park was conducted in order to determine why the design or certain specifications worked or did not work. The conclusions from the analysis provided recommendations that could provide insight on how to build safer jumps or explain why certain jumps were safely designed. Also, the views of different parties as related to the concept and idea of this research were presented in accordance with the results in order to understand how this research and the incorporated speed model could affect the culture of skiing from their point of view. After all the research has been analyzed conclusions were presented on how the results and technology developed through this research could affect the population involved in the field of terrain parks

4.1 Field Research

In order to find the information needed to troubleshoot the speed model test data was collected from three different Terrain Parks: Copper Mountain, Breckenridge Resort, and Sunday River. Jumps were randomly selected for measurement and the speeds for the jumps were read from skiers and snowboarders selected at random who were hitting the jump. The data that was needed for input into the model was taken from measuring the speed of the jumper, length from the jump to the landing hill, and angle dimensions of both the jump takeoff and landing. All data needed to be measured properly in order to be applicable for the speed model and was collected using certain materials.

4.1.1 Materials

To measure the speeds, lengths, and angles specific equipment was needed. The field research for this project was conducted using a Stabila Electronic Digital Level to measure angles, a Decatur ProSpeed Professional sports radar gun to read skier's and snowboarder's speeds, and a 100-ft. nylon surveying tape to measure lengths and distances.

4.1.1.1 Stabila Electronic Digital Level

The Stabila Electronic Digital Level was used to measure the angles of the jumps and the landing hill angles. The level was a length of 24" and gave a digital readout of the angle of the surface that the level was placed on. This tool was chosen because it could provide an angle reading quickly and the tool was user friendly. A picture of the level is seen below in Figure 4-1: Stabila Electronic Level.

Figure 4-1: Stabila Electronic Level

The Stabila Electronic Digital Level was described by the manufacturer as the following:

> Stabila's new 24" TECH level offers both a Stabila spirit level with patented vial system that is guaranteed accurate for life, and a dual display electronic level. The two digital displays are located on the top edge and the front face for easier and faster reads. The frame is 30% stronger than our previous electronic level and all four corners have been retained on the new frame. High accuracy electronic module: 0.05 degrees (1/16" over 72") and offers fast and easy one-button calibration. Electronic module reads in degrees, percentage or inches per foot so you can set slope and pitch. Audible tone on any selected degree for duplicating angles quickly without having to read the screen. Great for concrete contractors installing handicap ramps or any sidewalk or slab that needs specific angle or slope. Inspectors use electronic levels to check contractors work. Trim carpenters use electronic levels to determine angles on stairs to build railings. Framing carpenters use electronic levels to check pitches on existing roofs and duplicate pitches on common rafters, difficult rafters or valleys and crickets. All professional contractors appreciate the speed of the Stabila TECH level to increase productivity and accuracy.

The cost of the Stabila level was 149.99 and came with a carrying case. There was little difficulty in working with the tool or reading the data from the tool, thus it was very effective in providing the data for the model. 48” and 72” models are also available if the dimensions for the angles were wished to be measured in longer length.

4.1.1.2 Decatur ProSpeed Sports Radar Gun

The next piece of equipment that was used to obtain data for the model was the Decatur ProSpeed Sports Radar Gun. After researching a variety of speed guns at different price ranges it was found that the best applicable radar gun to retrieve the necessary was the Decatur ProSpeed Sports Radar Gun. A picture of the gun is seen below in Figure 4-2: Decatur ProSpeed Sports Radar Gun.

Figure 4-2: Decatur ProSpeed Sports Radar Gun

The Manufacturer's description of the radar gun is stated as:

> Decatur offers Professional Performance Sports Radar at an affordable price. Decatur Prospeed Sports Radar Gun is your only choice when it comes to functional! You can use Decatur Pro Speed Cordless Radar as a handheld radar gun , mount it on a tripod for continuous use, combine it with Decatur Speed Tracker Software for data collection and customized reports, or match it with Decatur Portable LED Sign for speed displays at special events.
> No other sports speed radar guns made comes close to matching the professional performance and affordable price of Decatur ProSpeed CR-1K Sports Radar. This Decatur Radar can measure the speed of almost anything that moves with pinpoint accuracy! Tracks peak and continuous speeds. Decatur Pro-Speed Sports Radar Gun is great for sports, fund raising and speed analysis!

Unlike other guns, the ProSpeed Sports Radar Gun had software that could be used with it in order to analyze and produce reports on the speeds being recorded. Despite these factors the software is able to do the following:

- Braking Tests
- 5 Graph Types
- Bounce Tests
- Stats Choose & View
- Grid Lines On/Off
- Comparison Graphing
- Real Time Speedometer
- Show Graph Coordinates
- Zero Point Reset
- Acceleration Tests
- Create and Compare Customized Graph

When analyzing speeds all of these features are highly useful for analysis, observation, and presentation of results. The radar gun use was user friendly, easy to read, and effective in its purpose of providing the necessary data for speeds.

Figure 4-3: Fiber Glass Tape Measurer

4.1.1.3 Fiber Glass Tape Measurer

The last piece of equipment that was used was a fiber glass measuring tape. The tape was 100’ long and was used to measure the length of the table of the jump and the jump height. The tape measurer was held in place by placing a ski pole in the open metal apparatus at the beginning of the tape measurer, refer to Figure 4-3: Fiber Glass Tape

Measurer below. The Metal apparatus at the end of the tape made measuring the needed measurements easy, especially if data collection was done alone.

4.1.2 Jump Data Collection

There were three different mountains which were approached to collect data from. Two of the three mountains, Copper and Breckenridge, were supportive of the research being conducted. Five different jumps were measured and three different jumps, two from Breckenridge and one from Copper Mountain returned usable data for the speed model. One of the jumps was used to troubleshoot the procedure upon which the data was collected and the other jump did not produced less than three riders and the data was not as useful as the other three jumps.

The two jumps from Breckenridge were slightly similar to one another but the jump from Copper was slightly different from the Breckenridge jumps. No one interrupted the data collection. People were often interested in what was being conducted and asked a variety of questions and every time had positive reactions to the concept and ideas of the research.

4.2 Speed Model

After various sessions of brainstorming it was found that the best way to approach developing safer designs for Terrain Parks was too look at how to design Terrain Park jumps. There were three different models that were developed throughout the project. The first model was based on determining the geometric design of a jump wheras the other two models were based on determining a speed for the jumper to place him/her in a safe range down the landing hill.

4.2.1 Geometrical Jump Design Model

The first attempt involved inputting hill geometries and specific jump attributes in order to determine optimal design criteria for other aspects of the jump. The input variables for the model were snow friction coefficient, pop height, incoming slope angle, jump angle, incoming slop length, and jump length. The output variables were table/gap length, landing slope length, transition velocity, launch velocity, pop velocity, final air velocity, and time in air to reach minimum and maximum landing areas. For an overview of the Geometrical Jump Design Model please refer to the Appendix.

The model assumed that air drag was negligible due to speeds rarely reaching above the 51 mph mark. The model assumed that the jumper was starting at the initial position on the hill in a stop position. Then based on snow friction coefficient, incoming hill length, and hill angle the initial velocity was determined. From the initial velocity the jumper's trajectory, speed, position in the air, and time to reach landing were determined. These factors were able to determine the additional geometric design of the jump.

From this model you can design a safe jump given the parameters of the existing ski hill, environment, and specified jump criteria. So if a park designer wanted to create a certain size jump given a certain ski hill, the model would output criteria which would allow the park designer to determine whether meeting the output criteria would be possible. This model is useful in the initial design of a Terrain Park jump but is not necessarily useful for everyday troubleshooting for speeds of Terrain Park jumps. The problem with this model was that it did not give insure safety for every jumper as the incoming speeds vary. In order to address these issue additional models were developed which looked at developing a model for the optimal incoming speed given the initial geometric design of a terrain park jump.

4.2.2 Terrain Park Speed Model (w/o pop)

This model was designed to be implemented after a jump was already made. It used the incoming speed, jump angle, distance from jump to landing hill, a skier's "pop" [1] height, and the angle of the landing hill to determine if the skier could reach the landing hill in a safe manner. Basic Newtonian physics, the research presented in the background section, and the Geometric Jump Design Model all provided the basis for which the model was designed.

This model allowed the user to input the jump length, jump angle, table length, landing hill length, and landing hill angle and the max required speed and a minimum required speed would be output from the model. The minimum speed was determined through setting the minimum landing area for the jumper at the knoll[2]. The maximum speed was determined by setting the maximum landing area for the jumper at the bottom of the landing hill length. The landing hill angles were measured until the angles started to level out. The landing hill length was determined through measuring all the angles of the hill but not including those where the change in angle was significant compared to previous angle measurements of the landing hill. The landing hill angle that was input was the average of all the measured landing hill angles.

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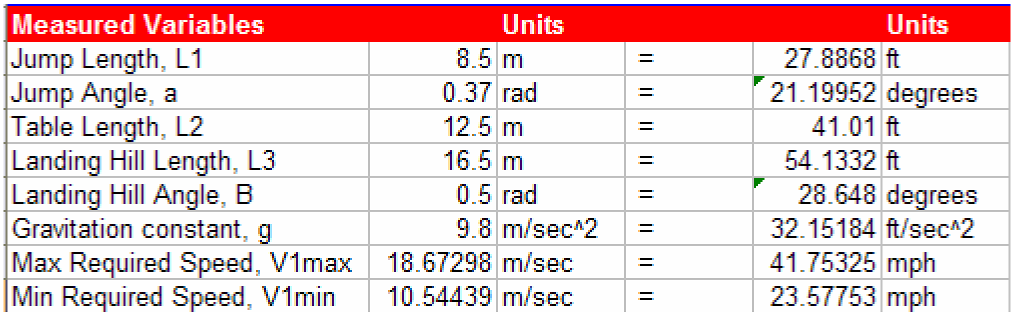
[1] "Pop" refers to the action which a jumper makes during the take-off phase of the jump

[2] Knoll – the area where the landing hill and the gap from the jump to the landing hill meet.



Measured Variables		Units			Units
Jump Length, L1	8.5	m	=	27.8868	ft
Jump Angle, a	0.37	rad	=	21.19952	degrees
Table Length, L2	12.5	m	=	41.01	ft
Landing Hill Length, L3	16.5	m	=	54.1332	ft
Landing Hill Angle, B	0.5	rad	=	28.648	degrees
Gravitation constant, g	9.8	m/sec^2	=	32.15184	ft/sec^2
Max Required Speed, V1max	18.67298	m/sec	=	41.75325	mph
Min Required Speed, V1min	10.54439	m/sec	=	23.57753	mph

Table 4-1: First Model Excel Inputs & Results

This model was an initial starting point for this model but did not consider important factors which have a large impact on determining a jumper’s initial safe speed. There were a few factors which were not included, which were as follows:

1. It did not consider the “pop” of a jumper
2. It did not consider the jump height
3. It did not represent the accurate landing hill angle.
4. The minimum and maximum speeds were not calculated appropriately because of missing data in their associated equations.
5. The change in height from the start of the landing hill to the end of the landing hill.

In order to address these issues which made the first model inaccurate a revised Terrain Park Speed Model was developed.

4.2.3 Revised Terrain Park Speed Model (w/pop)

The second Terrain Speed Model included more variables in its application and these were the jump height, jump length, landing hill length, jump takeoff angle, pop height, and the percentage of length desired down the landing. The jump height changed the model because it changed the trajectory of the jumper by placing him/her higher in the air at takeoff, thus placing them in a different area of the landing hill. The percentage of the landing hill was an adjustable variable, so if you put in 0% it would predict the speed for the rider at the knoll if 100% was the input it would predict the speed for the jumper to reach the bottom of the measured landing hill.

The model is designed so that the designed jump data (lengths & angles) can be input into the model and it will output a safe speed for that jump provided the inputted parameters. The model provided information on what an ideal range of speed would be for jumpers approaching the jump. Whether it is sunny, raining, snowing, or windy the minimum and maximum safe speeds are for any certain jump can be determined for any jumper.

The pop height of a jumper was a variable which affects the trajectory of the jumper. A jumper's pop height is directly related to their vertical jump. A vertical jump model which was developed by ExRx.net [14] which produces a person's projected average vertical jump based on their age, weight, height, and athletic ability[3]. This provided a range upon which the pop height used in the model was varied.

By considering all these variables the second speed model for Terrain Parks was developed. The notation by which the variables used in the model are listed below in Figure 4-5: Model 2 Input Variables. The values next to the variables are only examples of input values of the variables. Every variable besides the gravitation constant will vary from jump to jump.

The design for this specific speed model did not consider air drag because air drag only affects the speed of a skier after 51 mph, and the average terrain park jump does not require a speed that high. Another factor which can affect a skier's speed is an extreme

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[3] The world record for vertical jump is 46". This was also used in determining the affect of pop height on a the speed model.

wind gust once they are in the air or on the jump (a point in which their speed could change and not be altered by the skier due to their position on the jump or in the air). The speed model which was designed did not incorporate these two factors. An example of what the jumps looked like and the correlating measurement variables is provided below.

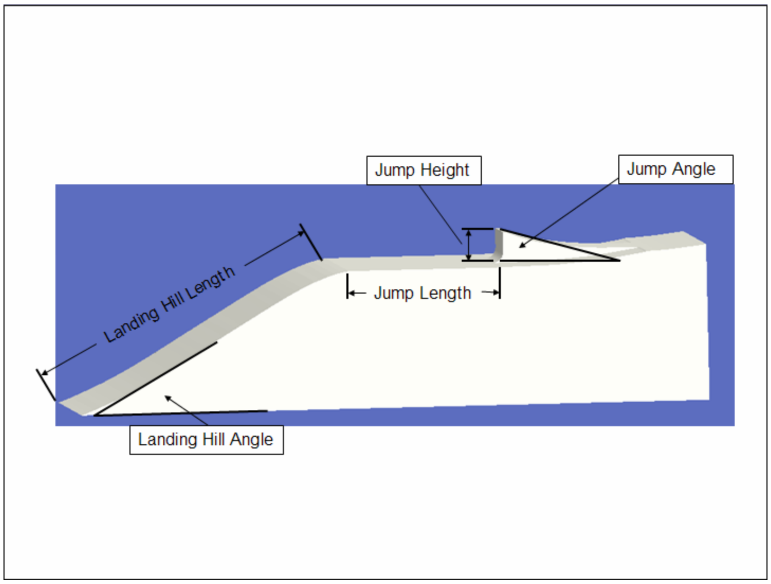
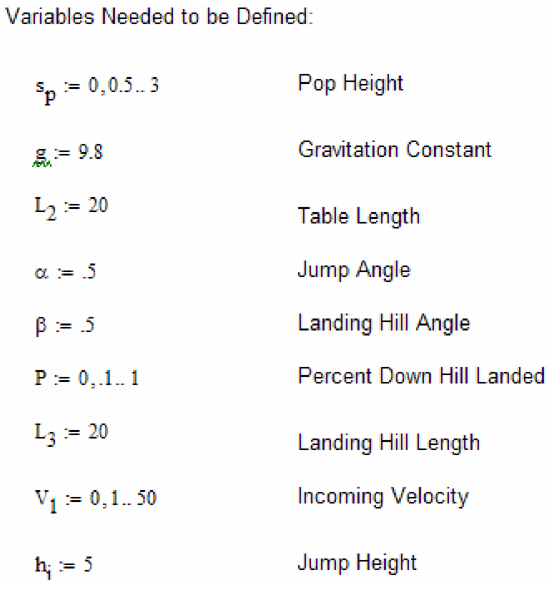


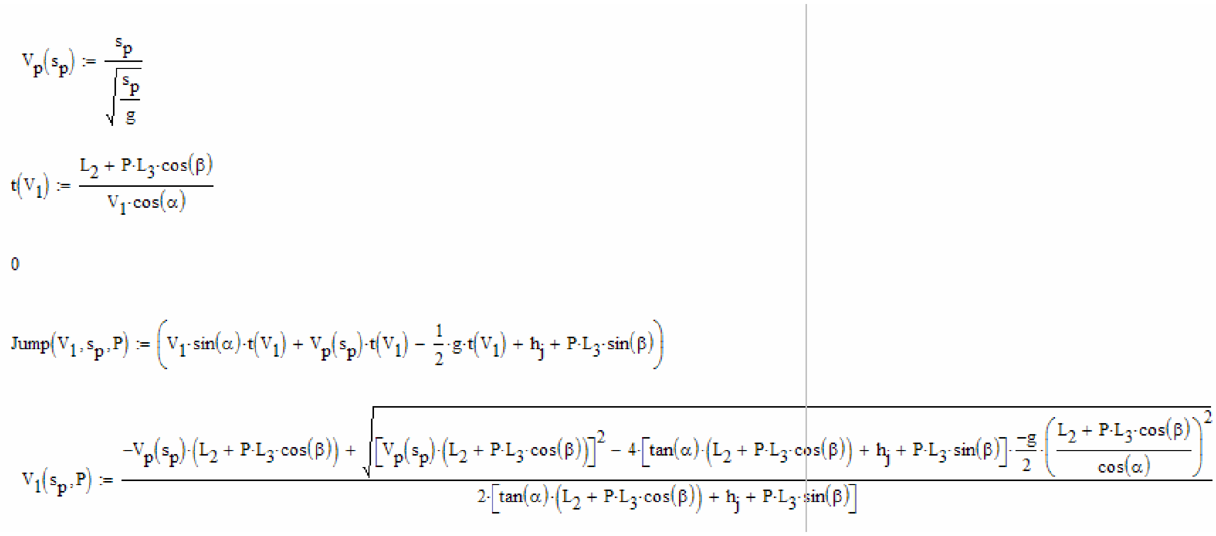
Figure 4-4: Jump Design Parameters


Variables Needed to be Defined:

$s_p := 0, 0.5 .. 3$	Pop Height
$g := 9.8$	Gravitation Constant
$L_2 := 20$	Table Length
$\alpha := .5$	Jump Angle
$\beta := .5$	Landing Hill Angle
$P := 0, .1 .. 1$	Percent Down Hill Landed
$L_3 := 20$	Landing Hill Length
$V_1 := 0, 1 .. 50$	Incoming Velocity
$h_j := 5$	Jump Height

Figure 4-5: Model 2 Input Variables

The equations which the model used in order to output the necessary speed is provided below. These equations are taken from basic Newtonian equations and then modified to incorporate the different variables related to Terrain Park Jumps.



$$V_p(s_p) := \frac{s_p}{\sqrt{\frac{s_p}{g}}}$$

$$t(V_1) := \frac{L_2 + P \cdot L_3 \cdot \cos(\beta)}{V_1 \cdot \cos(\alpha)}$$

$$0$$

$$\mathrm{Jump}(V_1, s_p, P) := \left(V_1 \cdot \sin(\alpha) \cdot t(V_1) + V_p(s_p) \cdot t(V_1) - \frac{1}{2} \cdot g \cdot t(V_1) + h_j + P \cdot L_3 \cdot \sin(\beta)\right)$$

$$V_1(s_p, P) := \frac{-V_p(s_p) \cdot (L_2 + P \cdot L_3 \cdot \cos(\beta)) + \sqrt{\left[V_p(s_p) \cdot (L_2 + P \cdot L_3 \cdot \cos(\beta))\right]^2 - 4 \cdot \left[\tan(\alpha) \cdot (L_2 + P \cdot L_3 \cdot \cos(\beta)) + h_j + P \cdot L_3 \cdot \sin(\beta)\right] \cdot \frac{-g}{2} \cdot \left(\frac{L_2 + P \cdot L_3 \cdot \cos(\beta)}{\cos(\alpha)}\right)^2}}{2 \cdot \left[\tan(\alpha) \cdot (L_2 + P \cdot L_3 \cdot \cos(\beta)) + h_j + P \cdot L_3 \cdot \sin(\beta)\right]}$$

Figure 4-6: Model 2 Calculations

From these calculations a graph like the one below can be derived which demonstrates how the percentage down the landing hill is affected according to the velocity and different pop heights.

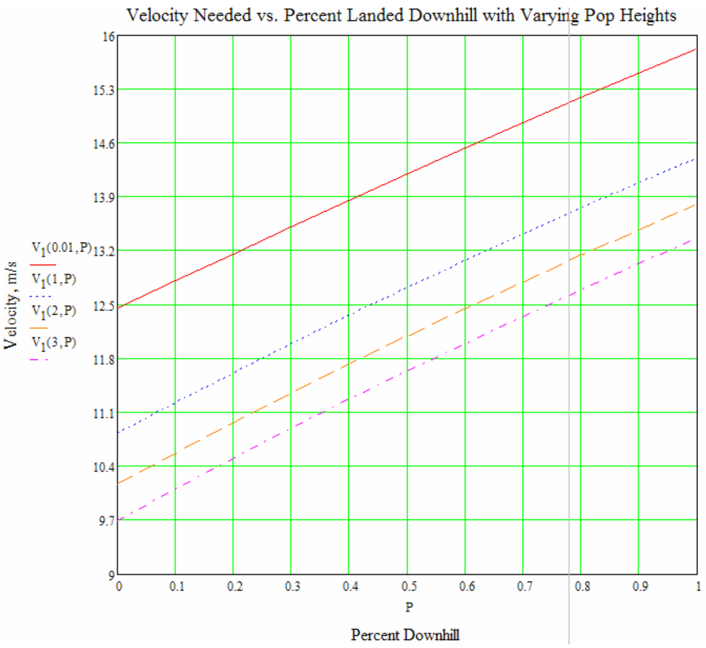


Figure 4-7: Example of graph derived from Model 2 Data

4.3 Questionnaires and Surveys

In addition to performing field research for this project surveys were done on mountain managers, ski patrollers, terrain park managers, and freestyle competitors & jumpers (See Appendix). General data was collected on the subject and various questions were asked in relation to safety, design, experience, and societal concerns related to Terrain Parks. This information was used in order to determine the perceived societal impact of technology on the design of Terrain Parks.

5 INVESTIGATION & ANALYSIS

This section provides an overview of the results that were recorded from the field testing at Breckenridge Resort and Copper Mountain, the application and results of the Speed Model, a series of graphical analyses of the Speed Model, and the results observed and collected from the questionnaires and surveys.

5.1 Field Research

The process of collecting and measuring the data (besides speeds) only took around 15-20 minutes on average for each jump. First the table lengths from the jump to start of the landing hill were measured and recorded. Second, the distance from the bottom of the jump base to the top of the lip was recorded. This process took about 2-3 minutes. Third, the angles of the jump were measured. By looking at the profile of the jump it can be seen where the transition from the inrun to the start of the jump is. The first angle measurement is taken from where the jump angle starts. Then a measurement is taken every 24” until the last angle of the jump is measured, which is the lip of the jump. Lastly, the angles of the landing hill are measured. Looking at where the hill starts to decline from a level degree is where the first measurement was taken. Measurements were taken every 24” successively from the initial landing hill starting point until the hill degree start to decrease from the median measurement of the landing hill data.

All the equipment and tools that were used for data collection were effective in obtaining the data needed and were easy to use. These two factors are important because the equipment that was used to obtain data for the speed model would have to be used by park managers and employees in order to utilize the speed model. Thus the effectiveness and ease of use of the equipment is important

The errors that can result from the collection of data are mostly due to human error. The radar gun came with a metal calibrator, which when hit produces a reading of 61 mph on the radar gun. The variation in data collected then mainly would be due to human error in relation to sight of measurements, inaccurate placing of tool, or misreading. The accuracy of the data collected could have been measured by performing numerous series of data collection on the same jump, but considering the data was being collected to be tested and that the data collection process was not being analyzed, performing various series was not necessary.

5.1.1 Jump Angles

An overview of how the jump angles for Breckenridge jump 1, Breckenridge Jump 2, and Copper Jump 1 are provided below. This graph demonstrates the how the angles change as the length of the jump increase. The graph shows that each jump is different from one another. The Copper jump is the longest jump but the Breckenridge jumps are slightly steeper and shorter. The design of the Breckenridge jumps is similar but jump 2 is larger than jump 1.

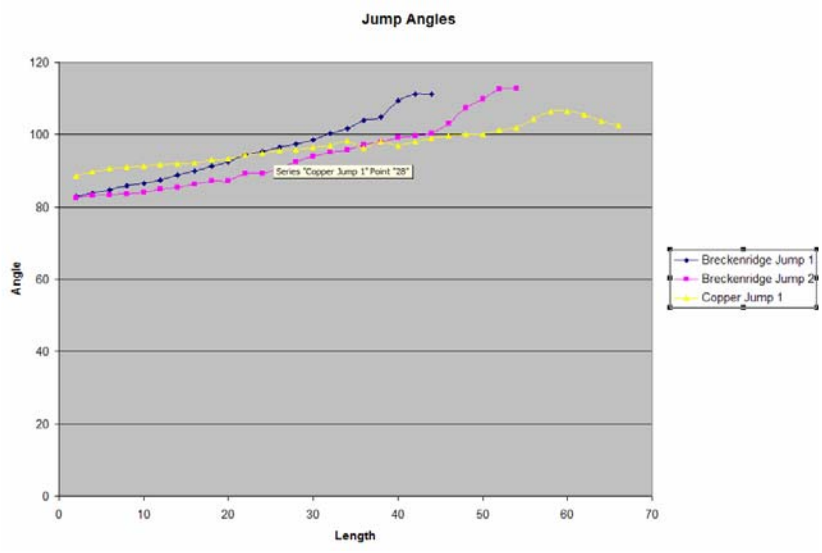


Figure 5-1: Graph of Jump Angles vs. Length

5.1.2 Landing Hill Angles

The landing hill angles were also measured. For all three jumps as the landing hill progressed in length the angle of the landing hill became steeper until a certain point where it started to decrease in steepness. At this point where the steepness of the landing hill began to level out it was determined that this was a critical point of the landing hill and it would not be safe for jumpers to land beyond that area. The measurements that were made in the field of the landing hill angles can be seen in the Appendix.

The range upon which the jumper landed down the landing hill was also recorded. By observation percentages of 0, 5, 10, 25, 50, and 66 were recorded in respect to the percentage of the jumper's landing on the hill. So if a jumper landed 0% downhill it meant that the jumper did not land on the landing hill and either hit the knoll or landed in the flat[4]. If a jumper's landing was recorded at 5% then it was observed that the jumper made it about 5% down the landing hill. The same procedure was performed for both

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[4] Flat - the flat area between the jump and the landing hill.

skiers and snowboarders. The results of these observations can be seen in the Appendix under Recorded Jump Speeds.

5.1.3 Speed Measurements

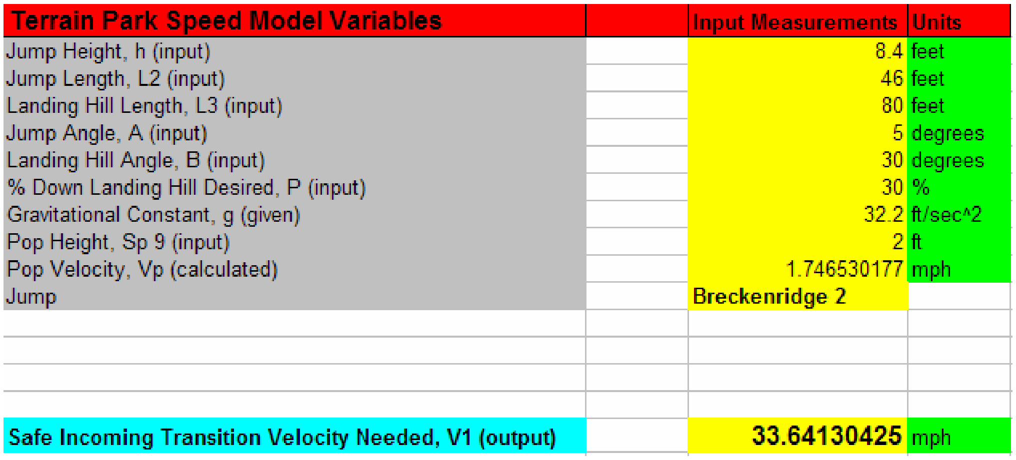
Speeds were also recorded from each jump at each mountain. There were over 50 observations total recorded from both snowboarders and skiers. Each speed had a correlated observed landing hill percentage that was also recorded. These measurements were recorded in order to perform a comparison to the predicted velocities and their correlating landing hill percentages.

5.2 Speed Model

The results from the field were used to analyze and produce realistic results from the Speed Model. The jump parameters that were measured on the different jumps at Breckenridge and Copper were applied to the model to produce the predicted velocity needed. Different variations of the model were created by changing the pop height in the model and the percentage down the landing hill. This section looks at the results from the model and presents an analysis of how the pop height, landing hill percentage, and the landing hill angle affect the predicted velocity output by the Speed Model. The results for the Speed Model were returned using Microsoft Excel and were then analyzed using Mathcad.

5.2.1 Model Results

The specifications for each jump at Breckenridge and Copper Mountain were used as inputs in the model and the outputs recorded as results. The model showed that given the measured parameters what the recommended safe speed would be. So if a jumper goes off the jump with no pop on the Breckenridge Jump 2 and would like to land from 0% to 100% down the landing hill the jumper's speed would need to be between 26 mph and 34 mph, with an increase of about 2.5 to 3mph per for every 25% increase down the landing hill. The world record for a person's vertical jump is almost 4 feet. The average vertical jump is quite lower than that and then adding the equipment onto a jumper the average vertical jump could possibly be around 9 inches. When this variable is input in the model it decreases the needed transition velocity for the jumper by about 1 mph as seen by the model. Below is an example of the model table which shows the different input, given, and output variables for the model. An overview of these results as they pertain to the Breckenridge Jump 2 can be seen in the Appendix.



Terrain Park Speed Model Variables		Input Measurements	Units
Jump Height, h (input)		8.4	feet
Jump Length, L2 (input)		46	feet
Landing Hill Length, L3 (input)		80	feet
Jump Angle, A (input)		5	degrees
Landing Hill Angle, B (input)		30	degrees
% Down Landing Hill Desired, P (input)		30	%
Gravitational Constant, g (given)		32.2	ft/sec^2
Pop Height, Sp 9 (input)		2	ft
Pop Velocity, Vp (calculated)		1.746530177	mph
Jump		**Breckenridge 2**	
Safe Incoming Transition Velocity Needed, V1 (output)		**33.64130425**	mph

Table 5-1: Terrain Park Speed Model (Excel)

Similar model results can be made with the other two jumps that were observed. The example provided here and the ones in the Appendix were chosen to demonstrate how the model changed as the percentage of landing hill changed and how adding a pop height variable affects the output speed of the model.

5.2.2 Graphical Analysis of Model

In MathCad the same model was input and various graphs were generated to demonstrate what the affect on the predicted speed output by the model by variations in pop height, landing hill percentage, and landing hill angle.

First a graph was generated for each jump which showed what the predicted velocity for a certain percentage down the landing hill. The first graph shows the predicted velocities for Breckenridge Jump 1. Graphs for the other two jumps can be seen in the Appendix under Predicted Velocity Breckenridge 2 and Predicted Velocity Copper Mountain Jump. could be completed and produce the same results in the manner that this graph was created.

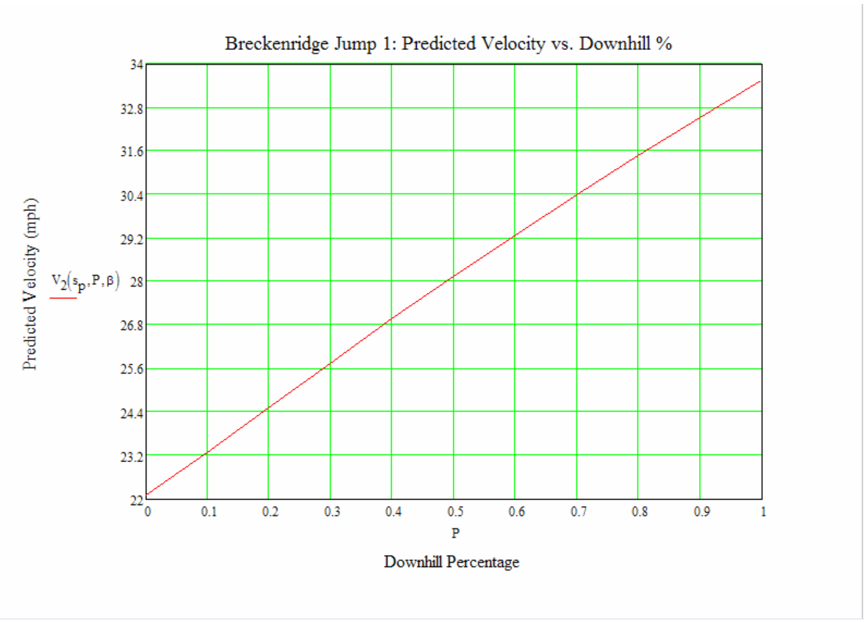


Figure 5-2: Graph of Predicted Velocity vs. Downhill Percentage

The percentage down hill graph demonstrates that as the jumper lands farther down the hill the correlating needed velocity increases and the less the jumper lands downhill the less the needed velocity is. The graph also demonstrates how the velocity needed is affected by no pop height to pop heights at about one foot intervals. What is interesting is that as the pop height increases its bearing on the necessary velocity decreases.

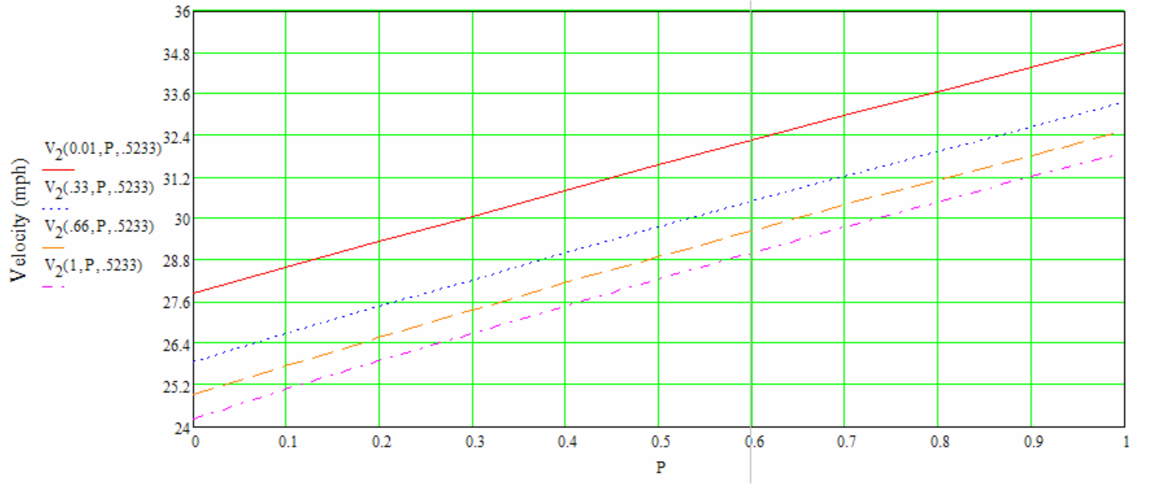


Figure 5-3: Velocity Needed v. % Down Landing Hill

The next graph, Figure 5-4: Landing Hill Angles v. Necessary Speed, Varying % Landing Downhill demonstrates how the velocity needed is affected by the landing hill angle. The different lines on the graph show the different percentages down the landing hill and how the velocity needed is also affected by this as it relates to the landing hill angle. From this graph it can be said that as the angle of the hill increases the velocity needed increases. Also as the percentage down the landing hill is increased the more drastic the change is in the velocity needed when compared to the landing hill angle.

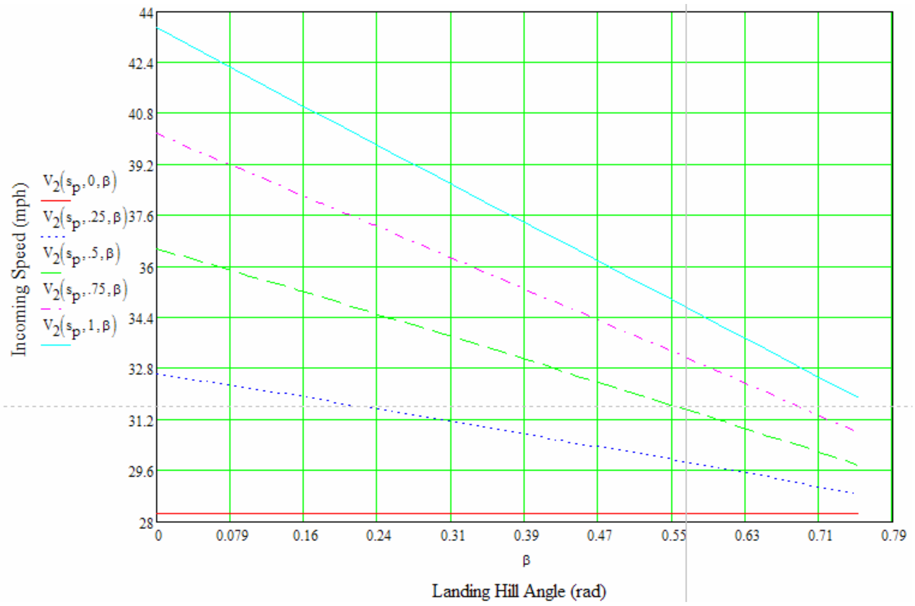


Figure 5-4: Landing Hill Angles v. Necessary Speed, Varying % Landing Downhill

A variety of graphs were derived which demonstrated how the predicted speed output by the Speed Model is affected by the pop height of a jumper, the percentage of landing hill, and the angle of the hill. These graphs show how the various design factors of a jump can greatly affect the required safe speed of a jump.

5.3 Questionnaires & Surveys

A variety of parties were interviewed on safety in terrain parks and their opinion on this research. Ski patrollers, mountain managers, competitors, and the general public were all questioned and surveyed on these two matters.

Most ski patrollers were interested in talking about the safety of terrain parks but most were reluctant to talk about specific injuries related to terrain parks and the circumstances surrounding them. Most responded that they would have to talk to their director in order to see if they were able to talk about the specifics relating to injuries in terrain parks.

Most mountain managers were not available to answer the surveys nor available to talk to. Although when sending out requests for comped ticket requests only 2 mountains approved the request and issued a ticket for research at no cost. These mountains were interested in the research and were willing to contribute.

All the competitors and athletes that were interviewed on these matters responded the same way in that they believe research of this manner would have a positive impact on terrain parks and newschool skiing and would make hitting jumps a lot less nerve racking and from their perspective more safe. All competitors says if they could know what the recommended speed was for any jump their worries of overshooting or undershooting a landing of a jump would be extremely reduced or nonexistent.

One of the biggest factors that were observed in relation to the societal implications and obstacles was the refusal of one mountain to produce a cost free lift ticket for research purposes. Sunday River Mountain Resort in Maine refused to issue a lift ticket for research purposes. The director of operations for the mountain said that he did not like the fact that there would be someone measuring the different specifications of the terrain park jumps and measuring incoming speeds of jumpers. A ticket was purchased instead and no research was conducted at the mountain. Ironically what was found by observation that the jumps were not designed well at all and around 80% of jumpers who hit the jumps undershot, overshot, or got hurt on the jumps. After witnessing the condition of the jumps and the results from jumper’s hitting them it could hypothesized that the reason the director of operations did not want someone researching their terrain park was because they knew the condition of them and did not want any bad results.

The responses and results from the questionnaires and interviews provided valuable insight in how the various parties which are involved in skiing culture, especially those directly affected and involved with terrain parks, view safety and research concerning terrain park jumps.

6 CONCLUSIONS

After researching a variety of methods that could be used to design terrain park jumps, it was found that the integration of a speed model which models the required incoming speed of a jumper would be optimal. The results from the field research were input into the model and the predicted incoming velocity for that jump was output. The surveys and interviews provided vital insight and information into understanding the societal implications and impact that integrating technology into Terrain Park Design.

6.1 Summary of Results

The speed model that was designed provided the velocity needed given certain jump specifications that were used as inputs in the model. The three variables which were found to vary the required incoming speed of the jumper were the pop height, landing hill angle, and the percentage landed downhill of the landing hill. It was found that as the pop height of the jumper increased the speed required landing a certain percentage down the landing hill decreased. Also as the pop height increased the variation in the amount of speed required for higher pop heights and preceding lower pop heights converged closer and closer to one another. What also was taken into consideration was how the angle of the landing hill affected the speed required. It was found that as the landing hill angle increased the speed required to landing a certain percentage down the landing hill decreased. A factor which magnified this affect was pop height. The factor by which the velocity needed changed as the angle of the landing hill increased when considering pop height was larger because the pop height affects the trajectory of the jumper.

Certain analyses that would have like to have been conducted were not possible. Because the landing hill percentages were only visually observed and the pop height of each rider was not able to be observed it was hard to determine the efficiency and feasibility of the Speed Model. Despite these issues, results were still produced and a graphical analysis of the results was conducted which demonstrated the way in which certain jump specifications affect how a jump can be designed.

Thus, the research of this project demonstrated that provided certain jump specifications a speed for a rider to land safely on the landing hill can be obtained. These results allow for the speeds for different sizes of jumps to be modeled and ultimately determine both a safe required speed for the jump and a safely designed jump. The research will be a starting point for providing recommendations for specifications for terrain park jumps and their associated safe speeds for skiers.

6.2 Societal Implications & Obstacles

The interviews and surveys that were conducted in conjunction with the research involving terrain park design provided insight and understanding to the current status of safety in terrain parks and this research. The majority of individuals agreed that terrain parks need to be safer and better designed. The one major obstacle that came out of this research was trying to understand and deal with why Sunday River Mountain Resort in Sunday River, ME did not want any research being conducted on their terrain parks. Is not facing the issues right in front of them make them not responsible for what is happening at their mountain or is it a form of negligence? If injury rates and results similar to the Salvini case are present it may be seen as negligence by some juries. Precedence set by the Salvini case, the positive reactions and opinions to terrain park research, and the desire for safer terrain parks should all be great motivation factors by society for ski resorts and event organizers to create safer terrain parks.

In addition to providing safe recommendations for parks the research could also be used by competitors, ski areas, and event organizers as a way to provide riders with a recommended safe speed for any terrain park jump. A speed trap could be set up on every jump along with an LCD panel displaying the rider's speed which would inform the rider before he or she went off of the jump what their speed was. This same procedure could be brought into ski area parks for permanent placement on all terrain park jumps to also provide recommended speeds for all terrain park guests.

6.3 Recommendations for Further Research

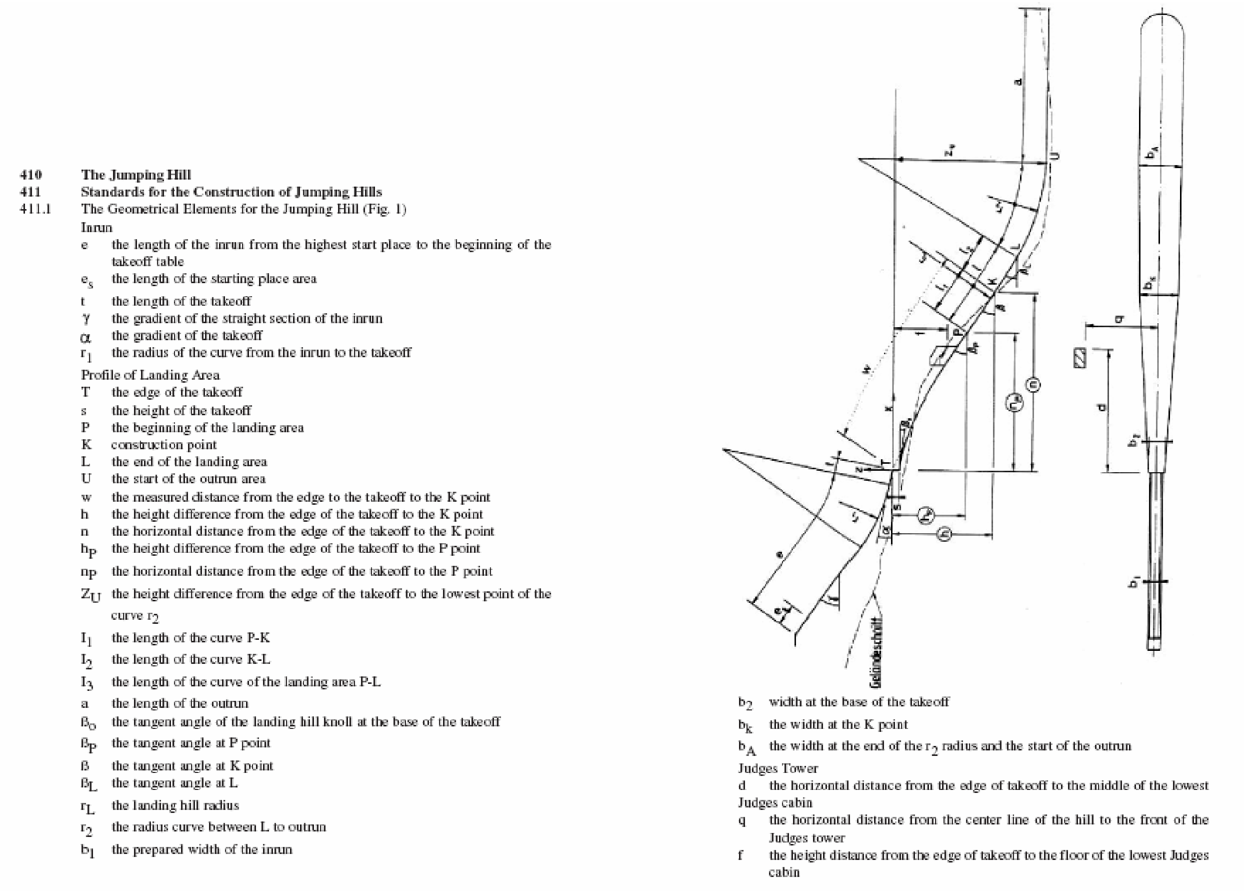
There are some recommendations which can be made for future research related to the design of terrain parks. Even though this research performed field research and produced a speed model, because the jumpers' percentage down the landing hill was not recorded accurately and their pop heights were not able to be measured it was hard to determine the efficiency and feasibility of the model. So some recommendations that could be made for future research would be to perform additional field research in the same manner done in this research project but determine ways in which to accurately record the jumper's percentage landed downhill and their pop height. If these two parameters could be measured and recorded it would produce more accurate data and enable for a more efficient and feasible analysis of the Speed Model.

Another aspect that was difficult in this project was using the software that came with the speed gun for measuring speeds on the mountain. Unfortunately, in order to run the program the gun had to be directly connected by the correlating connection cable for the program to a computer. Seeing how the research was being conducted on the ski mountain in varying conditions, it was not necessary optimal to have a computer connected to the speed gun, and thus makes utilizing the software difficult. Also the program is provided on a floppy disk, not a CD, and floppy disk drives are not as popular as CD drives, so it makes it more difficult to add the program to a recent laptop that could possibly be brought out onto the terrain park.

After more data was collected and the results analyzed in the model a possible correction coefficient could be developed which would account for any inaccuracies or discrepancies providing an optimal Speed Model for Terrain Park Jumps.

7 APPEDIX

1. FIS Jumping Hill Standards



410 The Jumping Hill

411 Standards for the Construction of Jumping Hills

411.1 The Geometrical Elements for the Jumping Hill (Fig. 1)

Inrun

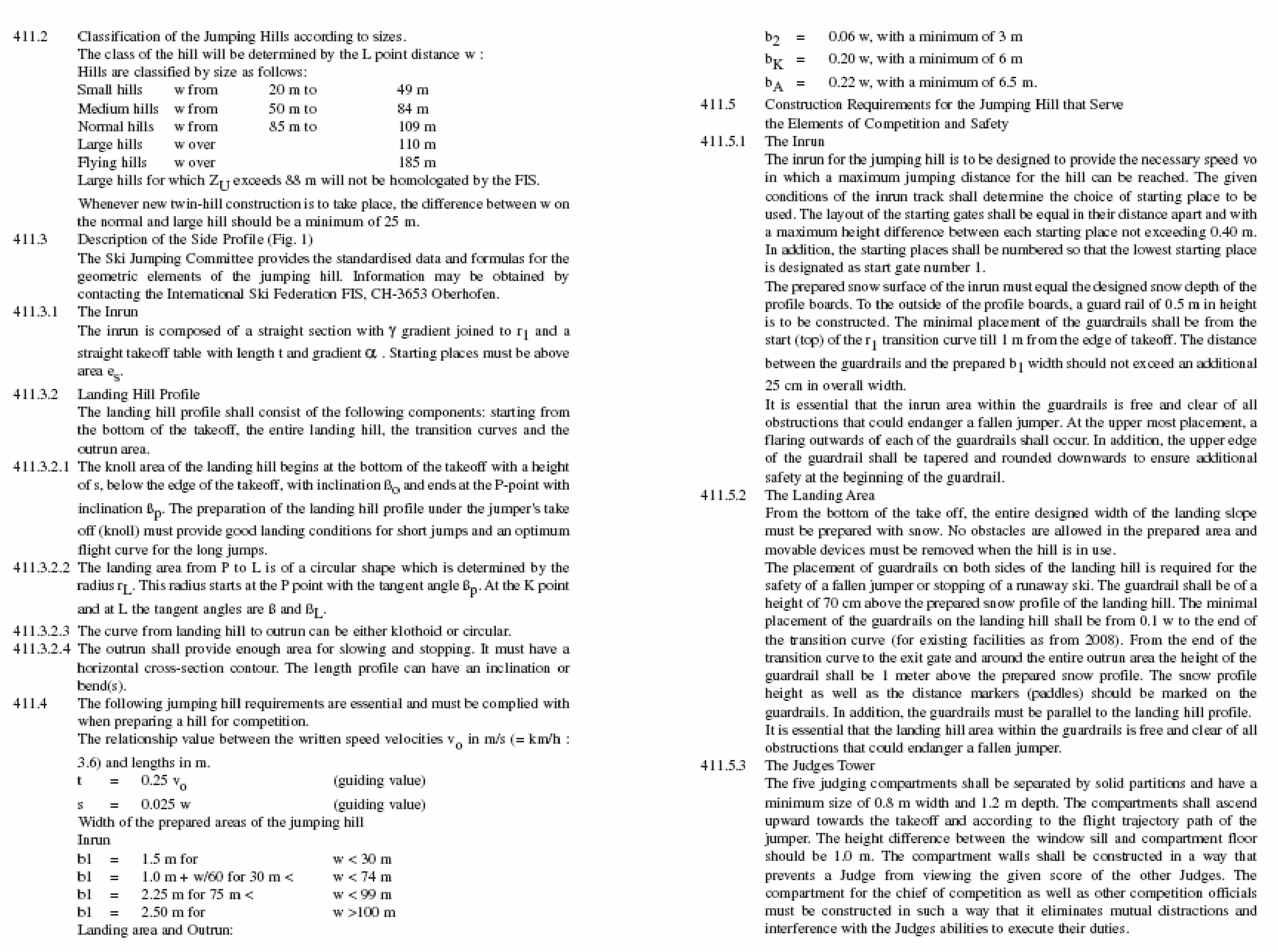
e	the length of the inrun from the highest start place to the beginning of the takeoff table
e_s	the length of the starting place area
t	the length of the takeoff
γ	the gradient of the straight section of the inrun
α	the gradient of the takeoff
r_1	the radius of the curve from the inrun to the takeoff

Profile of Landing Area

T	the edge of the takeoff
s	the height of the takeoff
P	the beginning of the landing area
K	construction point
L	the end of the landing area
U	the start of the outrun area
w	the measured distance from the edge to the takeoff to the K point
h	the height difference from the edge of the takeoff to the K point
n	the horizontal distance from the edge of the takeoff to the K point
h_P	the height difference from the edge of the takeoff to the P point
np	the horizontal distance from the edge of the takeoff to the P point
Z_U	the height difference from the edge of the takeoff to the lowest point of the curve r_2
I_1	the length of the curve P-K
I_2	the length of the curve K-L
I_3	the length of the curve of the landing area P-L
a	the length of the outrun
$ß_O$	the tangent angle of the landing hill knoll at the base of the takeoff
$ß_P$	the tangent angle at P point
ß	the tangent angle at K point
$ß_L$	the tangent angle at L
r_L	the landing hill radius
r_2	the radius curve between L to outrun
b_1	the prepared width of the inrun
b_2	width at the base of the takeoff
b_K	the width at the K point
b_A	the width at the end of the r_2 radius and the start of the outrun

Judges Tower

d	the horizontal distance from the edge of takeoff to the middle of the lowest Judges cabin
q	the horizontal distance from the center line of the hill to the front of the Judges tower
f	the height distance from the edge of takeoff to the floor of the lowest Judges cabin



411.2 Classification of the Jumping Hills according to sizes.

The class of the hill will be determined by the L point distance w :

Hills are classified by size as follows:

Small hills	w from	20 m to	49 m
Medium hills	w from	50 m to	84 m
Normal hills	w from	85 m to	109 m
Large hills	w over		110 m
Flying hills	w over		185 m

Large hills for which Z_U exceeds 88 m will not be homologated by the FIS.

Whenever new twin-hill construction is to take place, the difference between w on the normal and large hill should be a minimum of 25 m.

411.3 Description of the Side Profile (Fig. 1)

The Ski Jumping Committee provides the standardised data and formulas for the geometric elements of the jumping hill. Information may be obtained by contacting the International Ski Federation FIS, CH-3653 Oberhofen.

411.3.1 The Inrun

The inrun is composed of a straight section with γ gradient joined to r_1 and a straight takeoff table with length t and gradient α . Starting places must be above area e_s.

411.3.2 Landing Hill Profile

The landing hill profile shall consist of the following components: starting from the bottom of the takeoff, the entire landing hill, the transition curves and the outrun area.

411.3.2.1 The knoll area of the landing hill begins at the bottom of the takeoff with a height of s, below the edge of the takeoff, with inclination β_o and ends at the P-point with inclination β_P. The preparation of the landing hill profile under the jumper's take off (knoll) must provide good landing conditions for short jumps and an optimum flight curve for the long jumps.

411.3.2.2 The landing area from P to L is of a circular shape which is determined by the radius r_L. This radius starts at the P point with the tangent angle β_P. At the K point and at L the tangent angles are β and β_L.

411.3.2.3 The curve from landing hill to outrun can be either klothoid or circular.

411.3.2.4 The outrun shall provide enough area for slowing and stopping. It must have a horizontal cross-section contour. The length profile can have an inclination or bend(s).

411.4 The following jumping hill requirements are essential and must be complied with when preparing a hill for competition.

The relationship value between the written speed velocities v_o in m/s (= km/h : 3.6) and lengths in m.

$t = 0.25\ v_o$ (guiding value)

$s = 0.025\ w$ (guiding value)

Width of the prepared areas of the jumping hill

Inrun

b1 = 1.5 m for w < 30 m

b1 = 1.0 m + w/60 for 30 m < w < 74 m

b1 = 2.25 m for 75 m < w < 99 m

b1 = 2.50 m for w >100 m

Landing area and Outrun:

b_2 = 0.06 w, with a minimum of 3 m

b_K = 0.20 w, with a minimum of 6 m

b_A = 0.22 w, with a minimum of 6.5 m.

411.5 Construction Requirements for the Jumping Hill that Serve the Elements of Competition and Safety

411.5.1 The Inrun

The inrun for the jumping hill is to be designed to provide the necessary speed vo in which a maximum jumping distance for the hill can be reached. The given conditions of the inrun track shall determine the choice of starting place to be used. The layout of the starting gates shall be equal in their distance apart and with a maximum height difference between each starting place not exceeding 0.40 m. In addition, the starting places shall be numbered so that the lowest starting place is designated as start gate number 1.

The prepared snow surface of the inrun must equal the designed snow depth of the profile boards. To the outside of the profile boards, a guard rail of 0.5 m in height is to be constructed. The minimal placement of the guardrails shall be from the start (top) of the r_1 transition curve till 1 m from the edge of takeoff. The distance between the guardrails and the prepared b_1 width should not exceed an additional 25 cm in overall width.

It is essential that the inrun area within the guardrails is free and clear of all obstructions that could endanger a fallen jumper. At the upper most placement, a flaring outwards of each of the guardrails shall occur. In addition, the upper edge of the guardrail shall be tapered and rounded downwards to ensure additional safety at the beginning of the guardrail.

411.5.2 The Landing Area

From the bottom of the take off, the entire designed width of the landing slope must be prepared with snow. No obstacles are allowed in the prepared area and movable devices must be removed when the hill is in use.

The placement of guardrails on both sides of the landing hill is required for the safety of a fallen jumper or stopping of a runaway ski. The guardrail shall be of a height of 70 cm above the prepared snow profile of the landing hill. The minimal placement of the guardrails on the landing hill shall be from 0.1 w to the end of the transition curve (for existing facilities as from 2008). From the end of the transition curve to the exit gate and around the entire outrun area the height of the guardrail shall be 1 meter above the prepared snow profile. The snow profile height as well as the distance markers (paddles) should be marked on the guardrails. In addition, the guardrails must be parallel to the landing hill profile.

It is essential that the landing hill area within the guardrails is free and clear of all obstructions that could endanger a fallen jumper.

411.5.3 The Judges Tower

The five judging compartments shall be separated by solid partitions and have a minimum size of 0.8 m width and 1.2 m depth. The compartments shall ascend upward towards the takeoff and according to the flight trajectory path of the jumper. The height difference between the window sill and compartment floor should be 1.0 m. The compartment walls shall be constructed in a way that prevents a Judge from viewing the given score of the other Judges. The compartment for the chief of competition as well as other competition officials must be constructed in such a way that it eliminates mutual distractions and interference with the Judges abilities to execute their duties.

414 The Approval of Jumping Hills

Jumping competitions listed in the FIS Calendar may be carried out only on jumping hills with current FIS approval and an official hill certificate.

The Sub-Committee for Jumping Hills provides certificates for normal, large, and Ski Flying hills.

Small and medium jumping hills must be homologated by National Ski Associations if no international competitions are to be arranged. Standards of National Ski Associations for small and medium size hills can deviate from FIS standards.

The new standards are valid for jumping hills that will be built or reconstructed after January 1, 2001. Certificates for jumping hills awarded by the FIS before January 1, 2001 on the basis of the pre-existing construction standards are still valid.

414.1 New or Reconstructed Jumping Hills

414.1.1 Before the start of hill construction, the owners of the jump hill must submit their plans to the hosting National Ski Association. The plans are then submitted for approval to the chairman of the Sub-Committee of Jumping Hills. This process shall be done for both new and reconstructed jumping hills. It is a submission requirement to submit 3 copies of the plans, 1:500 scale, including both profile and aerial view of the proposed jumping hill.

In addition to the construction plans, the submitted plan must include a certified meteorological survey by a state certified agency, institute or business. The survey shall provide data on both the snow and the wind conditions of the proposed site. The report information shall be taken at the following site placement.

Accurate wind data shall be measured and recorded at the site plan location between the takeoff of the jump and the landing hill area. The time period to be recorded is from the beginning of December to the end of March. Wind data to be measured shall be both wind direction and wind velocity. The wind velocity shall be measured in m/s.

In general, site selection, planning, and jump complex design should maintain, respect, and comply with both conservation and environmental ideals.

414.1.2 The chairman of the Sub-Committee for Jumping Hills is authorised to grant preliminary construction permission if FIS standards for jumping hills (art. 411) are completely met and the meteorological report is complete and positive. The chairman will then inform the other members of the Sub-Committee for Jumping Hills of these actions and add the application to the agenda for discussion and final approval at the Sub-Committee's next meeting.

414.1.3 Whenever applications do not meet FIS standards for the construction of jumping hills (art. 411), the Sub-Committee for Jumping Hills must decide whether to grant permission for the construction of the hill during one of its upcoming meetings.

The Sub-Committee for Jumping Hills may grant permission for deviations from FIS standards for the construction of jumping hills if convincing reasons for the deviation are firmly supported and jumpers' safety can be guaranteed through the trouble-free sport-technical performance of the jumps.

414.2 The Homologation of Jumping Hills

414.2.1 After completing construction, renovation, or correction to a jumping hill, the National Ski Association is responsible for applying for the homologation of that jumping hill to the Chairman of the Sub-Committee for Jumping Hills. The application must include three copies of the profile and vertical views to the scale of 1:500. The correctness of the plans must be verified by an authorised professional survey agency or department.

414.2.2 For all jumping hills with plastic mats, meant to host international competitions, a second profile certificate is required. The special plastic hill certificate must be displayed next to the original hill certificate. The hill owner must apply for an approval for the plastic covering. The chairman of the Sub-Committee for Jumping Hills appoints a member of his Sub-Committee to inspect the facility. If the facility conforms to the Ski Jumping hill rules and special rules (art. 412), the chairman of the Sub-Committee will award the certificate.

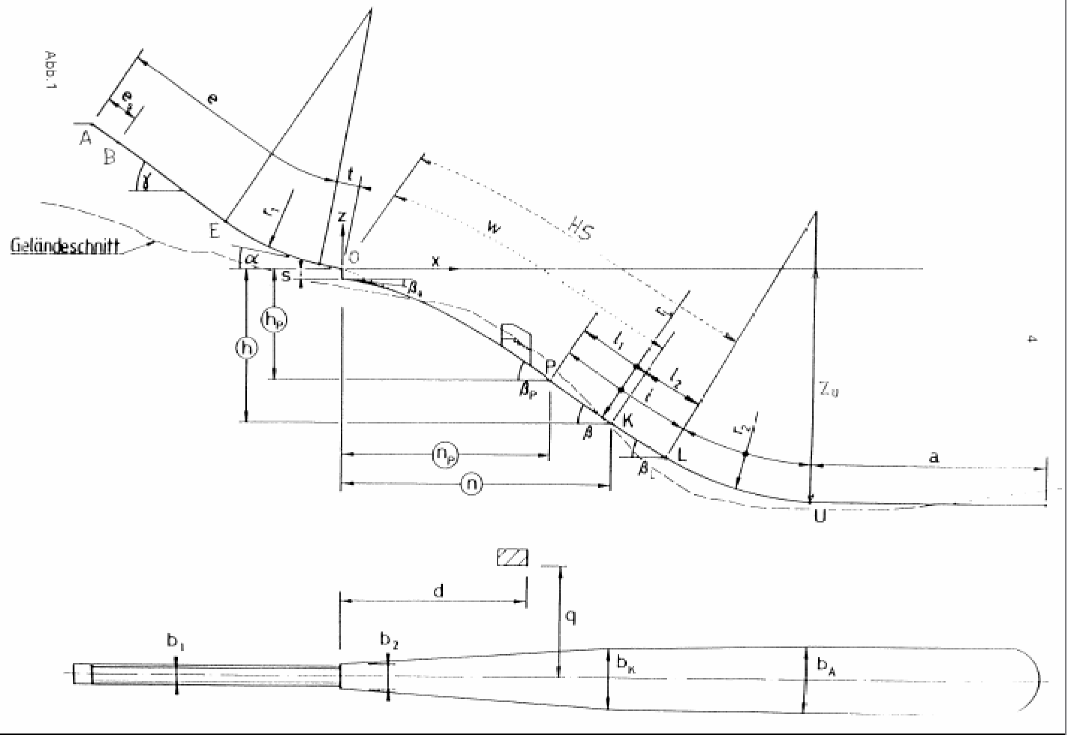
414.2.3 After the plans have been reviewed, the Chairman of the Sub-Committee for Jumping Hills shall personally work out the hill certificate for hill profiles that are in agreement with FIS construction standards.

In the case of profiles with deviations from FIS standards, the chairman must decide

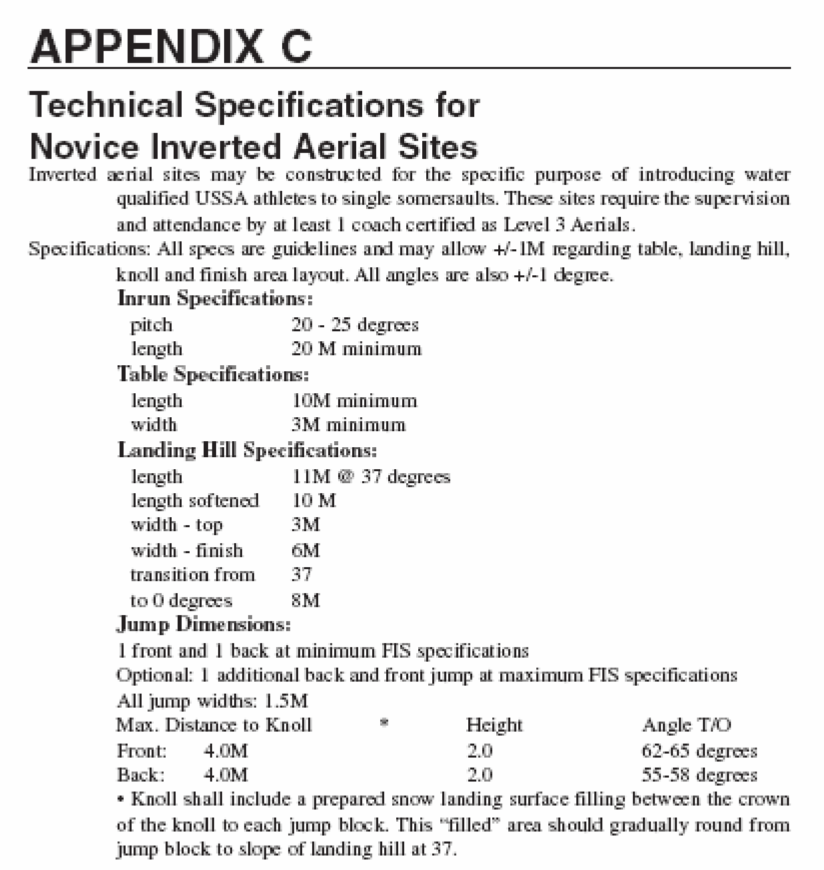
- whether to grant conditional permission that enforces the necessary changes through a process of review, control, and responsibility by the proposed hill's National Ski Association
- whether further review and inspection by a certified hill inspector is necessary
- whether an exceptional permission should be reviewed (art. 414.1.3).

414.2.4 The Sub-Committee for Jumping Hills may decide during one of its regular meeting on the homologations of jumping hills after renovations or corrections to profiles have occurred. The decisions of the Committee will be based on the verified application, profile sketches, and profile measurements submitted to the chairman.

414.2.5 Hill certificates are valid for five years. An application for additional extension is needed after five years. When no changes or renovations have occurred in the hill



2. USSA Freestyle Inverted Aerial Specifications



APPENDIX C

Technical Specifications for Novice Inverted Aerial Sites

Inverted aerial sites may be constructed for the specific purpose of introducing water qualified USSA athletes to single somersaults. These sites require the supervision and attendance by at least 1 coach certified as Level 3 Aerials.

Specifications: All specs are guidelines and may allow +/-1M regarding table, landing hill, knoll and finish area layout. All angles are also +/-1 degree.

Inrun Specifications:

pitch	20 - 25 degrees
length	20 M minimum

Table Specifications:

length	10M minimum
width	3M minimum

Landing Hill Specifications:

length	11M @ 37 degrees
length softened	10 M
width - top	3M
width - finish	6M
transition from	37
to 0 degrees	8M

Jump Dimensions:

1 front and 1 back at minimum FIS specifications

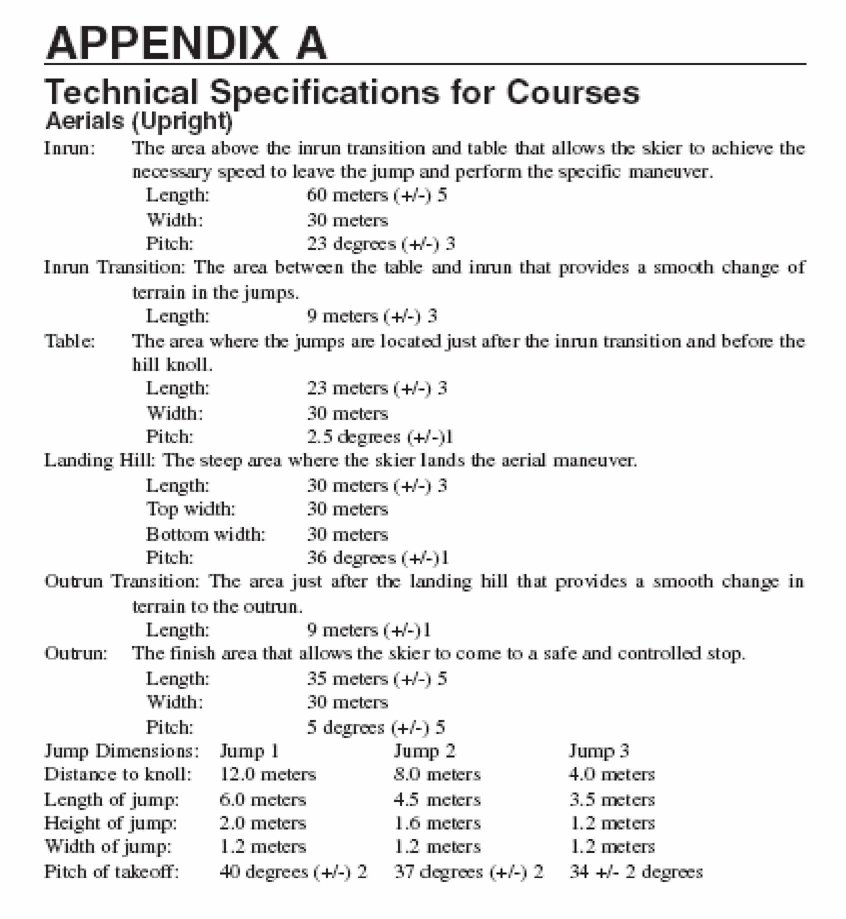
Optional: 1 additional back and front jump at maximum FIS specifications

All jump widths: 1.5M

Max. Distance to Knoll	*	Height	Angle T/O
Front: 4.0M		2.0	62-65 degrees
Back: 4.0M		2.0	55-58 degrees

• Knoll shall include a prepared snow landing surface filling between the crown of the knoll to each jump block. This "filled" area should gradually round from jump block to slope of landing hill at 37.

3. USSA Slopestyle & Big Air Specifications



APPENDIX A

Technical Specifications for Courses

Aerials (Upright)

Inrun: The area above the inrun transition and table that allows the skier to achieve the necessary speed to leave the jump and perform the specific maneuver.
Length: 60 meters (+/-) 5
Width: 30 meters
Pitch: 23 degrees (+/-) 3

Inrun Transition: The area between the table and inrun that provides a smooth change of terrain in the jumps.
Length: 9 meters (+/-) 3

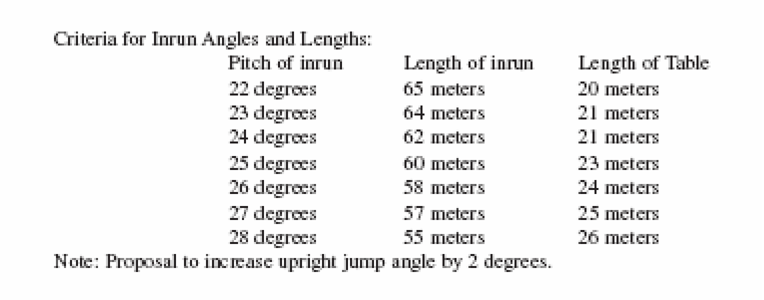
Table: The area where the jumps are located just after the inrun transition and before the hill knoll.
Length: 23 meters (+/-) 3
Width: 30 meters
Pitch: 2.5 degrees (+/-)1

Landing Hill: The steep area where the skier lands the aerial maneuver.
Length: 30 meters (+/-) 3
Top width: 30 meters
Bottom width: 30 meters
Pitch: 36 degrees (+/-)1

Outrun Transition: The area just after the landing hill that provides a smooth change in terrain to the outrun.
Length: 9 meters (+/-)1

Outrun: The finish area that allows the skier to come to a safe and controlled stop.
Length: 35 meters (+/-) 5
Width: 30 meters
Pitch: 5 degrees (+/-) 5

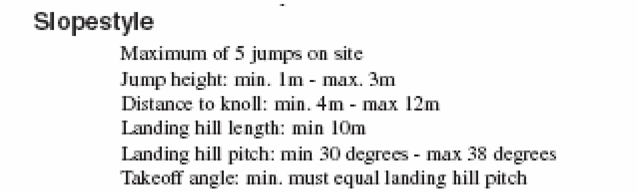
Jump Dimensions:	Jump 1	Jump 2	Jump 3
Distance to knoll:	12.0 meters	8.0 meters	4.0 meters
Length of jump:	6.0 meters	4.5 meters	3.5 meters
Height of jump:	2.0 meters	1.6 meters	1.2 meters
Width of jump:	1.2 meters	1.2 meters	1.2 meters
Pitch of takeoff:	40 degrees (+/-) 2	37 degrees (+/-) 2	34 +/- 2 degrees



Criteria for Inrun Angles and Lengths:

Pitch of inrun	Length of inrun	Length of Table
22 degrees	65 meters	20 meters
23 degrees	64 meters	21 meters
24 degrees	62 meters	21 meters
25 degrees	60 meters	23 meters
26 degrees	58 meters	24 meters
27 degrees	57 meters	25 meters
28 degrees	55 meters	26 meters

Note: Proposal to increase upright jump angle by 2 degrees.



Slopestyle

Maximum of 5 jumps on site
Jump height: min. 1m - max. 3m
Distance to knoll: min. 4m - max 12m
Landing hill length: min 10m
Landing hill pitch: min 30 degrees - max 38 degrees
Takeoff angle: min. must equal landing hill pitch

4. Terrain Park Signage

Figure 7-1

Figure 7-2

Figure 7-3

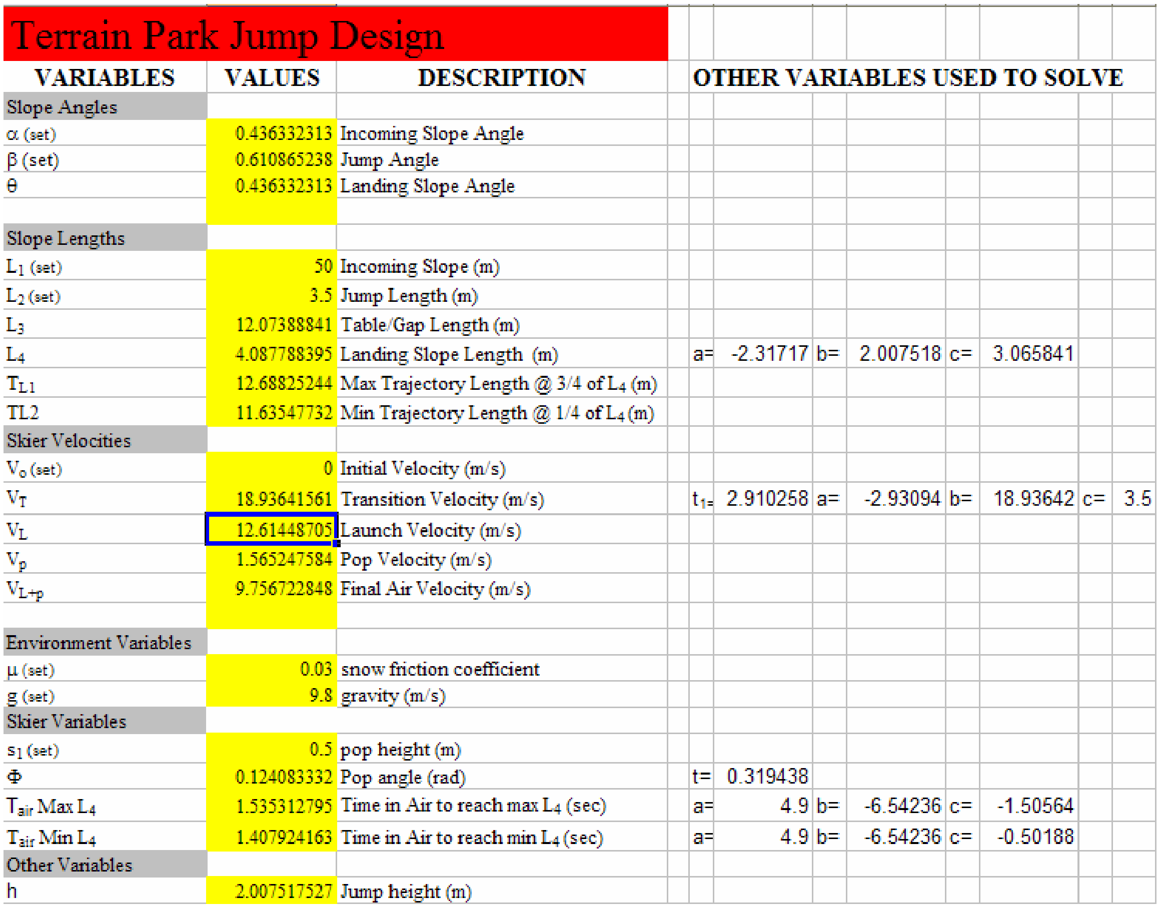
Figure 7-4

Figure 7-5

Figure 7-6

Figure 7-7

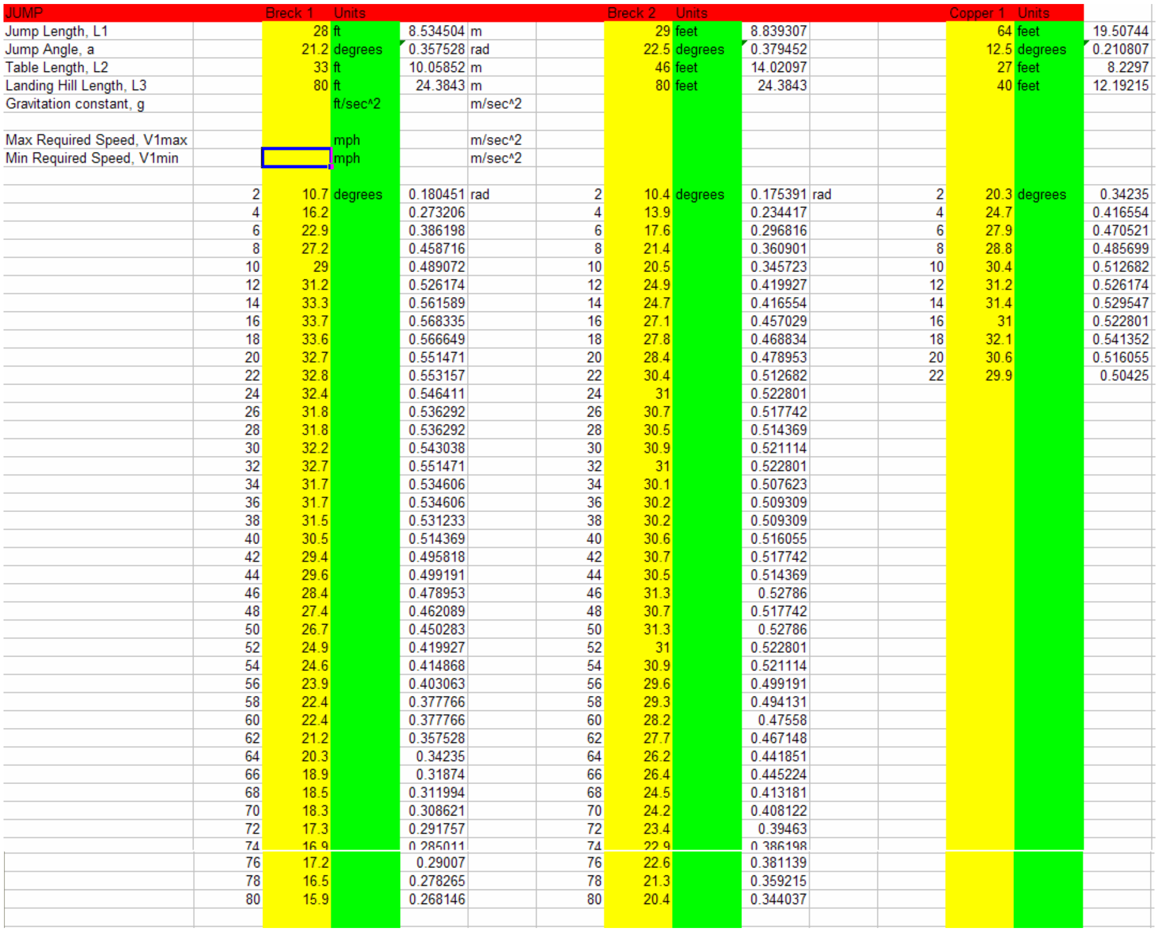
5. Geometric Jump Design Model



Terrain Park Jump Design

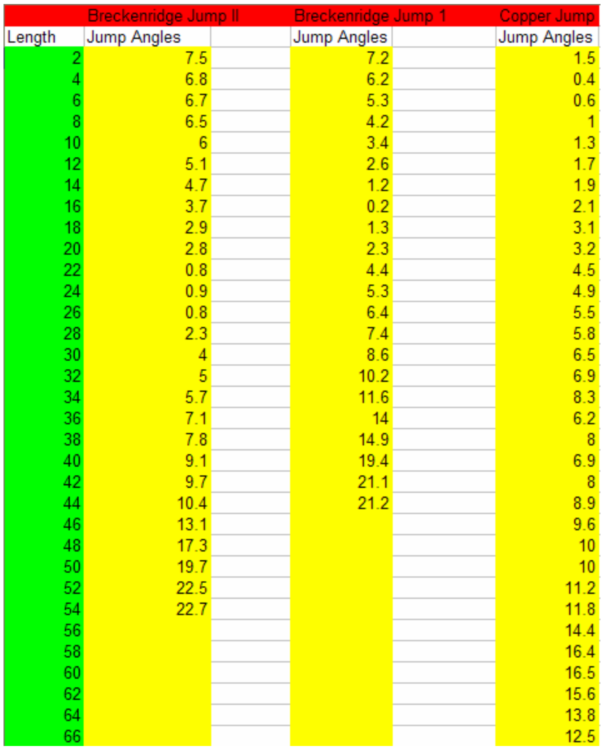
VARIABLES	VALUES	DESCRIPTION	OTHER VARIABLES USED TO SOLVE							
Slope Angles										
α (set)	0.436332313	Incoming Slope Angle								
β (set)	0.610865238	Jump Angle								
θ	0.436332313	Landing Slope Angle								
Slope Lengths										
L_1 (set)	50	Incoming Slope (m)								
L_2 (set)	3.5	Jump Length (m)								
L_3	12.07388841	Table/Gap Length (m)								
L_4	4.087788395	Landing Slope Length (m)	a=	-2.31717	b=	2.007518	c=	3.065841		
T_{L1}	12.68825244	Max Trajectory Length @ 3/4 of L_4 (m)								
TL2	11.63547732	Min Trajectory Length @ 1/4 of L_4 (m)								
Skier Velocities										
V_o (set)	0	Initial Velocity (m/s)								
V_T	18.93641561	Transition Velocity (m/s)	t_1=	2.910258	a=	-2.93094	b=	18.93642	c=	3.5
V_L	12.61448705	Launch Velocity (m/s)								
V_p	1.565247584	Pop Velocity (m/s)								
V_{L+p}	9.756722848	Final Air Velocity (m/s)								
Environment Variables										
μ (set)	0.03	snow friction coefficient								
g (set)	9.8	gravity (m/s)								
Skier Variables										
s_1 (set)	0.5	pop height (m)								
Φ	0.124083332	Pop angle (rad)	t=	0.319438						
T_{air} Max L_4	1.535312795	Time in Air to reach max L_4 (sec)	a=	4.9	b=	-6.54236	c=	-1.50564		
T_{air} Min L_4	1.407924163	Time in Air to reach min L_4 (sec)	a=	4.9	b=	-6.54236	c=	-0.50188		
Other Variables										
h	2.007517527	Jump height (m)								

6. Field Jump Landing Hill & Jump Spec Data



JUMP		Breck 1	Units				Breck 2	Units				Copper 1	Units	
Jump Length, L1		28	ft	8.534504	m		29	feet	8.839307			64	feet	19.50744
Jump Angle, a		21.2	degrees	0.357528	rad		22.5	degrees	0.379452			12.5	degrees	0.210807
Table Length, L2		33	ft	10.05852	m		46	feet	14.02097			27	feet	8.2297
Landing Hill Length, L3		80	ft	24.3843	m		80	feet	24.3843			40	feet	12.19215
Gravitation constant, g			ft/sec^2		m/sec^2									
Max Required Speed, V1max			mph		m/sec^2									
Min Required Speed, V1min			mph		m/sec^2									
	2	10.7	degrees	0.180451	rad	2	10.4	degrees	0.175391	rad	2	20.3	degrees	0.34235
	4	16.2		0.273206		4	13.9		0.234417		4	24.7		0.416554
	6	22.9		0.386198		6	17.6		0.296816		6	27.9		0.470521
	8	27.2		0.458716		8	21.4		0.360901		8	28.8		0.485699
	10	29		0.489072		10	20.5		0.345723		10	30.4		0.512682
	12	31.2		0.526174		12	24.9		0.419927		12	31.2		0.526174
	14	33.3		0.561589		14	24.7		0.416554		14	31.4		0.529547
	16	33.7		0.568335		16	27.1		0.457029		16	31		0.522801
	18	33.6		0.566649		18	27.8		0.468834		18	32.1		0.541352
	20	32.7		0.551471		20	28.4		0.478953		20	30.6		0.516055
	22	32.8		0.553157		22	30.4		0.512682		22	29.9		0.50425
	24	32.4		0.546411		24	31		0.522801					
	26	31.8		0.536292		26	30.7		0.517742					
	28	31.8		0.536292		28	30.5		0.514369					
	30	32.2		0.543038		30	30.9		0.521114					
	32	32.7		0.551471		32	31		0.522801					
	34	31.7		0.534606		34	30.1		0.507623					
	36	31.7		0.534606		36	30.2		0.509309					
	38	31.5		0.531233		38	30.2		0.509309					
	40	30.5		0.514369		40	30.6		0.516055					
	42	29.4		0.495818		42	30.7		0.517742					
	44	29.6		0.499191		44	30.5		0.514369					
	46	28.4		0.478953		46	31.3		0.52786					
	48	27.4		0.462089		48	30.7		0.517742					
	50	26.7		0.450283		50	31.3		0.52786					
	52	24.9		0.419927		52	31		0.522801					
	54	24.6		0.414868		54	30.9		0.521114					
	56	23.9		0.403063		56	29.6		0.499191					
	58	22.4		0.377766		58	29.3		0.494131					
	60	22.4		0.377766		60	28.2		0.47558					
	62	21.2		0.357528		62	27.7		0.467148					
	64	20.3		0.34235		64	26.2		0.441851					
	66	18.9		0.31874		66	26.4		0.445224					
	68	18.5		0.311994		68	24.5		0.413181					
	70	18.3		0.308621		70	24.2		0.408122					
	72	17.3		0.291757		72	23.4		0.39463					
	74	16.9		0.285011		74	22.9		0.386198					
	76	17.2		0.29007		76	22.6		0.381139					
	78	16.5		0.278265		78	21.3		0.359215					
	80	15.9		0.268146		80	20.4		0.344037					

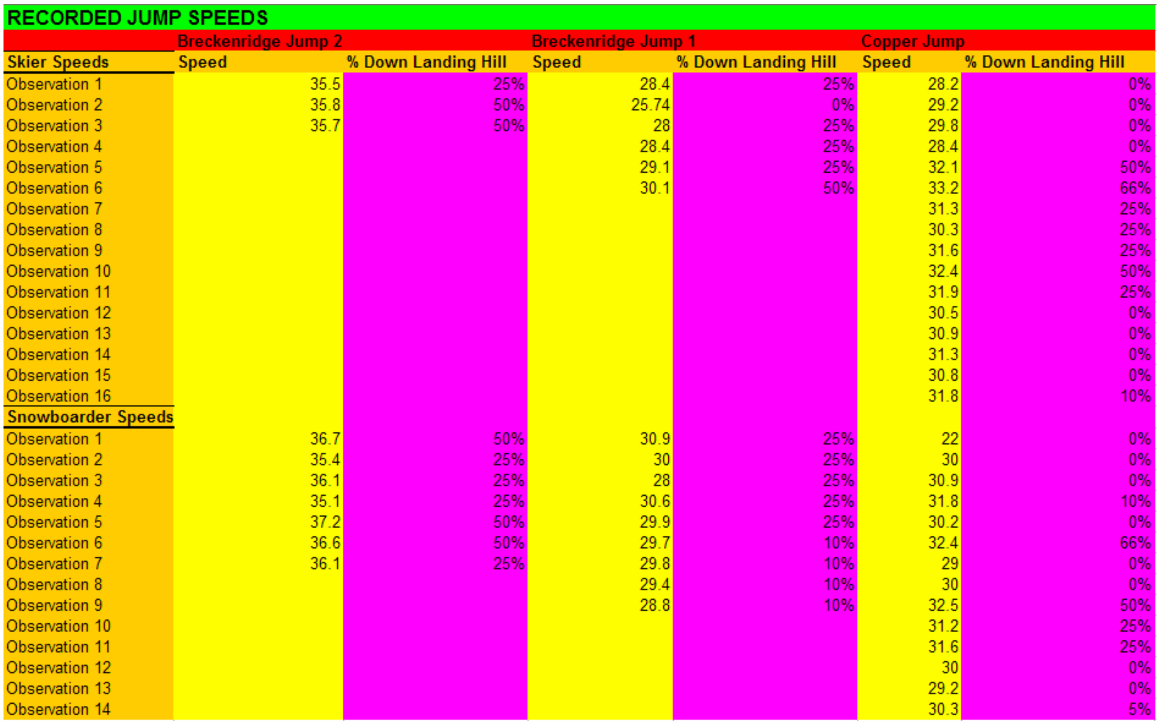
7. Field Test Jump Angle Data



	Breckenridge Jump II		Breckenridge Jump 1		Copper Jump
Length	Jump Angles		Jump Angles		Jump Angles
2	7.5		7.2		1.5
4	6.8		6.2		0.4
6	6.7		5.3		0.6
8	6.5		4.2		1
10	6		3.4		1.3
12	5.1		2.6		1.7
14	4.7		1.2		1.9
16	3.7		0.2		2.1
18	2.9		1.3		3.1
20	2.8		2.3		3.2
22	0.8		4.4		4.5
24	0.9		5.3		4.9
26	0.8		6.4		5.5
28	2.3		7.4		5.8
30	4		8.6		6.5
32	5		10.2		6.9
34	5.7		11.6		8.3
36	7.1		14		6.2
38	7.8		14.9		8
40	9.1		19.4		6.9
42	9.7		21.1		8
44	10.4		21.2		8.9
46	13.1				9.6
48	17.3				10
50	19.7				10
52	22.5				11.2
54	22.7				11.8
56					14.4
58					16.4
60					16.5
62					15.6
64					13.8
66					12.5

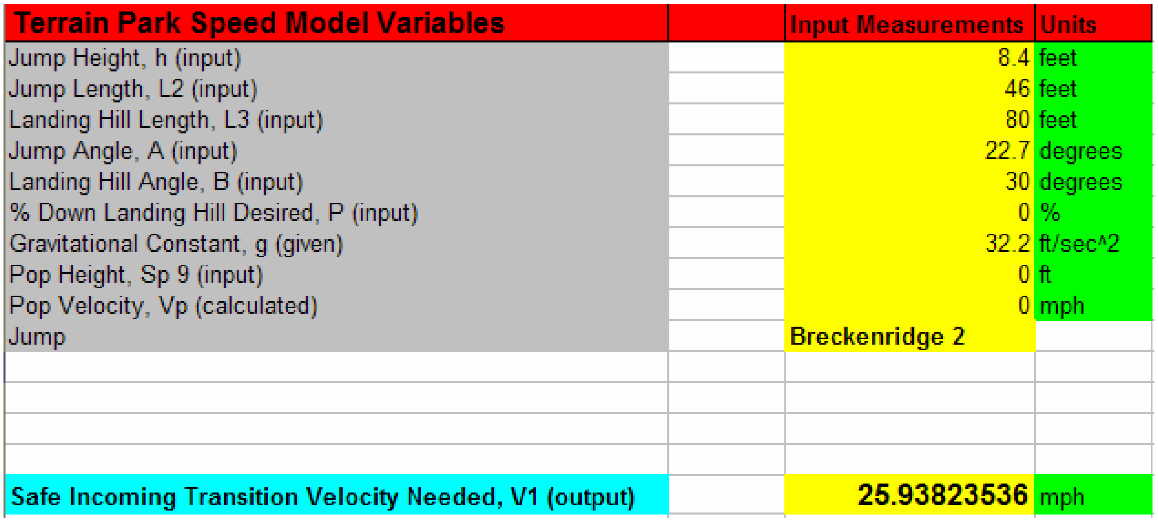
Figure 7-8: Field Test Data

8. Recorded Jump Speeds



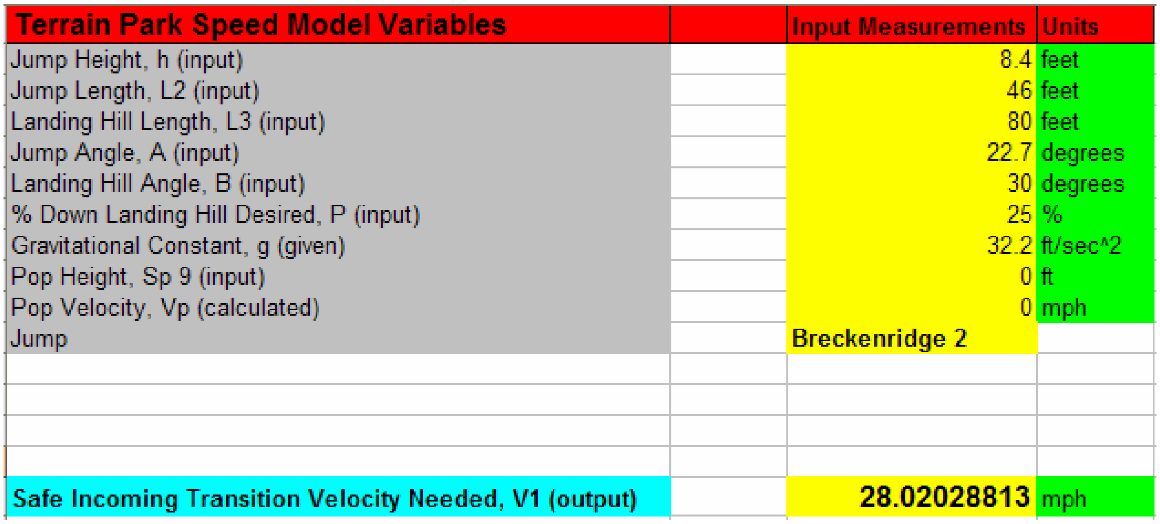
RECORDED JUMP SPEEDS						
	Breckenridge Jump 2		Breckenridge Jump 1		Copper Jump	
Skier Speeds	Speed	% Down Landing Hill	Speed	% Down Landing Hill	Speed	% Down Landing Hill
Observation 1	35.5	25%	28.4	25%	28.2	0%
Observation 2	35.8	50%	25.74	0%	29.2	0%
Observation 3	35.7	50%	28	25%	29.8	0%
Observation 4			28.4	25%	28.4	0%
Observation 5			29.1	25%	32.1	50%
Observation 6			30.1	50%	33.2	66%
Observation 7					31.3	25%
Observation 8					30.3	25%
Observation 9					31.6	25%
Observation 10					32.4	50%
Observation 11					31.9	25%
Observation 12					30.5	0%
Observation 13					30.9	0%
Observation 14					31.3	0%
Observation 15					30.8	0%
Observation 16					31.8	10%
Snowboarder Speeds						
Observation 1	36.7	50%	30.9	25%	22	0%
Observation 2	35.4	25%	30	25%	30	0%
Observation 3	36.1	25%	28	25%	30.9	0%
Observation 4	35.1	25%	30.6	25%	31.8	10%
Observation 5	37.2	50%	29.9	25%	30.2	0%
Observation 6	36.6	50%	29.7	10%	32.4	66%
Observation 7	36.1	25%	29.8	10%	29	0%
Observation 8			29.4	10%	30	0%
Observation 9			28.8	10%	32.5	50%
Observation 10					31.2	25%
Observation 11					31.6	25%
Observation 12					30	0%
Observation 13					29.2	0%
Observation 14					30.3	5%

9. Breckenridge Jump 2 w/o pop 0% landing hill



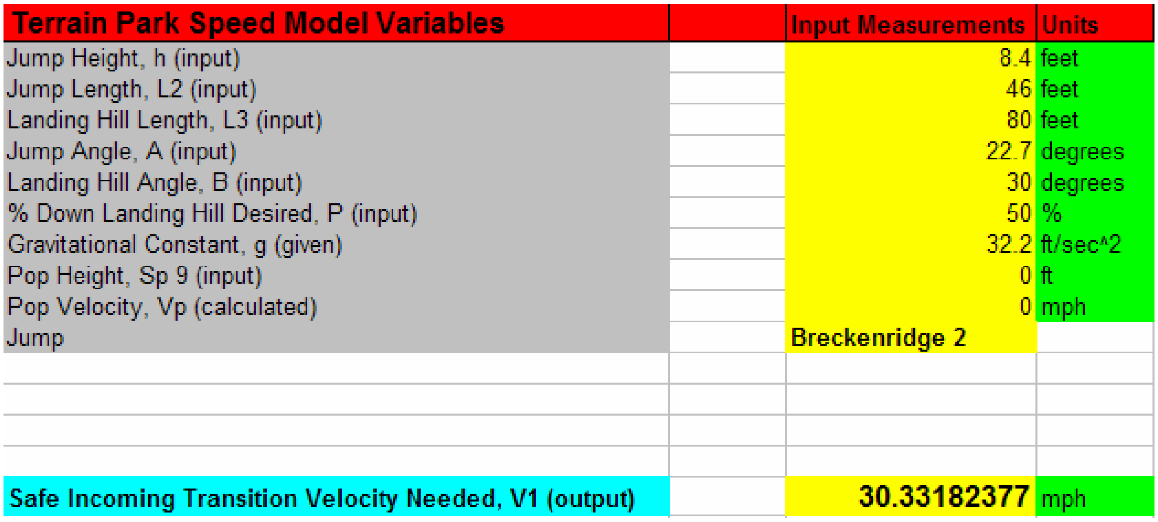
Terrain Park Speed Model Variables		**Input Measurements**	**Units**
Jump Height, h (input)		8.4	feet
Jump Length, L2 (input)		46	feet
Landing Hill Length, L3 (input)		80	feet
Jump Angle, A (input)		22.7	degrees
Landing Hill Angle, B (input)		30	degrees
% Down Landing Hill Desired, P (input)		0	%
Gravitational Constant, g (given)		32.2	ft/sec^2
Pop Height, Sp 9 (input)		0	ft
Pop Velocity, Vp (calculated)		0	mph
Jump		**Breckenridge 2**	
Safe Incoming Transition Velocity Needed, V1 (output)		**25.93823536**	mph

10. Breckenridge Jump 2 w/o Pop 25% Landing Hill



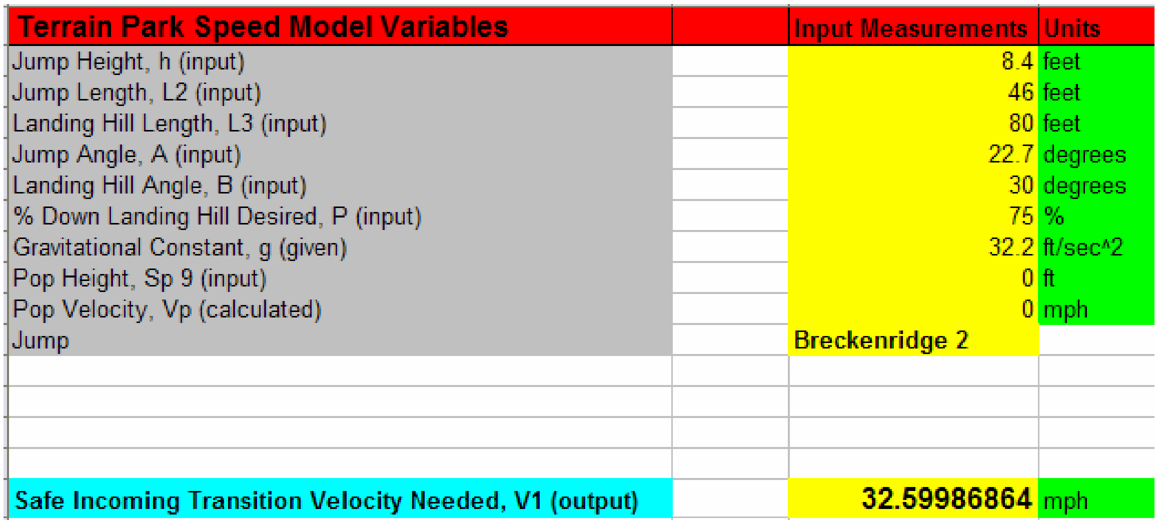
Terrain Park Speed Model Variables		**Input Measurements**	**Units**
Jump Height, h (input)		8.4	feet
Jump Length, L2 (input)		46	feet
Landing Hill Length, L3 (input)		80	feet
Jump Angle, A (input)		22.7	degrees
Landing Hill Angle, B (input)		30	degrees
% Down Landing Hill Desired, P (input)		25	%
Gravitational Constant, g (given)		32.2	ft/sec^2
Pop Height, Sp 9 (input)		0	ft
Pop Velocity, Vp (calculated)		0	mph
Jump		**Breckenridge 2**	
Safe Incoming Transition Velocity Needed, V1 (output)		**28.02028813**	mph

11. Breckenridge Jump 2 w/o pop 50% landing hill



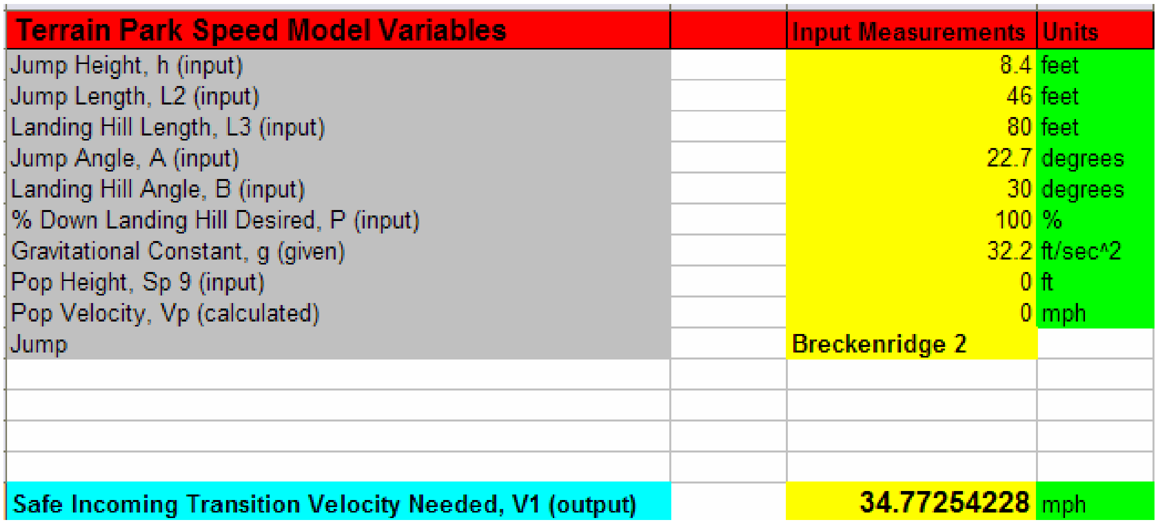
Terrain Park Speed Model Variables		Input Measurements	Units
Jump Height, h (input)		8.4	feet
Jump Length, L2 (input)		46	feet
Landing Hill Length, L3 (input)		80	feet
Jump Angle, A (input)		22.7	degrees
Landing Hill Angle, B (input)		30	degrees
% Down Landing Hill Desired, P (input)		50	%
Gravitational Constant, g (given)		32.2	ft/sec^2
Pop Height, Sp 9 (input)		0	ft
Pop Velocity, Vp (calculated)		0	mph
Jump		Breckenridge 2	
Safe Incoming Transition Velocity Needed, V1 (output)		**30.33182377**	mph

12. Breckenridge Jump 2 w/o pop 75% landing hill



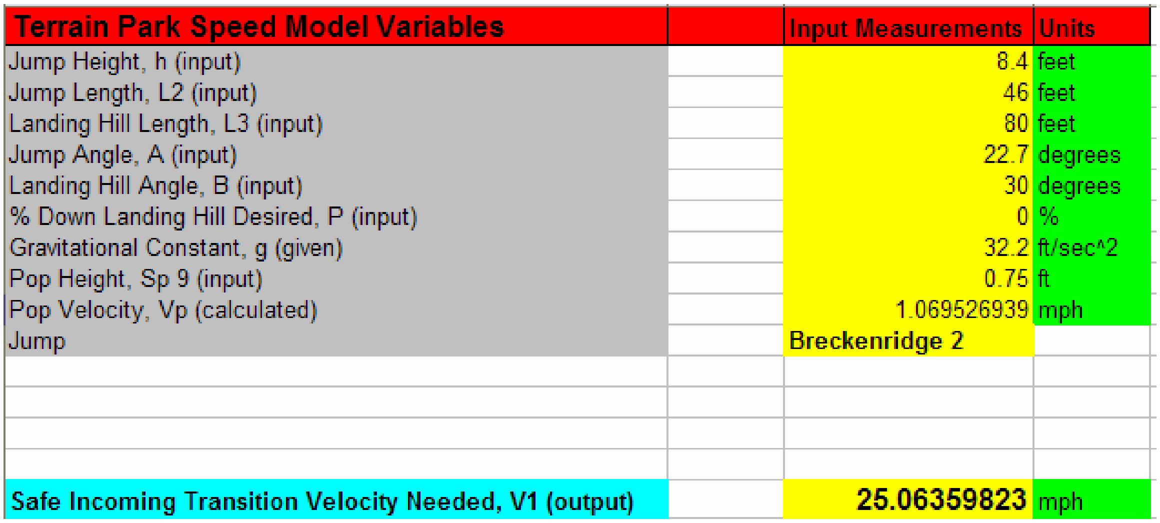
Terrain Park Speed Model Variables		Input Measurements	Units
Jump Height, h (input)		8.4	feet
Jump Length, L2 (input)		46	feet
Landing Hill Length, L3 (input)		80	feet
Jump Angle, A (input)		22.7	degrees
Landing Hill Angle, B (input)		30	degrees
% Down Landing Hill Desired, P (input)		75	%
Gravitational Constant, g (given)		32.2	ft/sec^2
Pop Height, Sp 9 (input)		0	ft
Pop Velocity, Vp (calculated)		0	mph
Jump		Breckenridge 2	
Safe Incoming Transition Velocity Needed, V1 (output)		**32.59986864**	mph

13. Breckenridge Jump 2 w/o pop 100% landing hill



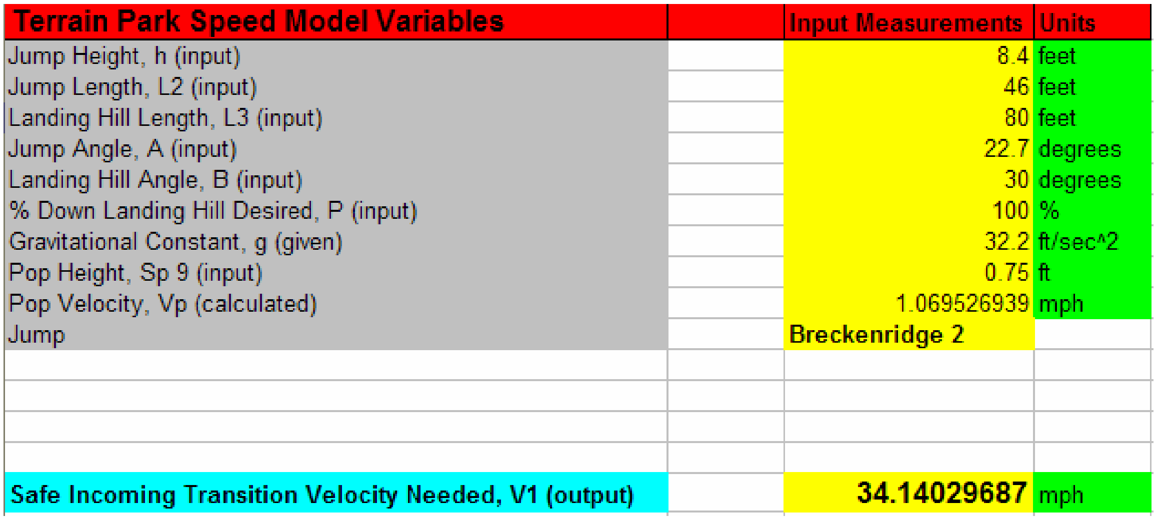
Terrain Park Speed Model Variables		Input Measurements	Units
Jump Height, h (input)		8.4	feet
Jump Length, L2 (input)		46	feet
Landing Hill Length, L3 (input)		80	feet
Jump Angle, A (input)		22.7	degrees
Landing Hill Angle, B (input)		30	degrees
% Down Landing Hill Desired, P (input)		100	%
Gravitational Constant, g (given)		32.2	ft/sec^2
Pop Height, Sp 9 (input)		0	ft
Pop Velocity, Vp (calculated)		0	mph
Jump		Breckenridge 2	
Safe Incoming Transition Velocity Needed, V1 (output)		**34.77254228**	mph

14. Breckenridge Jump 2 w/average pop 0% landing hill



Terrain Park Speed Model Variables		Input Measurements	Units
Jump Height, h (input)		8.4	feet
Jump Length, L2 (input)		46	feet
Landing Hill Length, L3 (input)		80	feet
Jump Angle, A (input)		22.7	degrees
Landing Hill Angle, B (input)		30	degrees
% Down Landing Hill Desired, P (input)		0	%
Gravitational Constant, g (given)		32.2	ft/sec^2
Pop Height, Sp 9 (input)		0.75	ft
Pop Velocity, Vp (calculated)		1.069526939	mph
Jump		Breckenridge 2	
Safe Incoming Transition Velocity Needed, V1 (output)		**25.06359823**	mph

15. Breckenridge Jump 2 w/average pop 100% landing hill



Terrain Park Speed Model Variables		Input Measurements	Units
Jump Height, h (input)		8.4	feet
Jump Length, L2 (input)		46	feet
Landing Hill Length, L3 (input)		80	feet
Jump Angle, A (input)		22.7	degrees
Landing Hill Angle, B (input)		30	degrees
% Down Landing Hill Desired, P (input)		100	%
Gravitational Constant, g (given)		32.2	ft/sec^2
Pop Height, Sp 9 (input)		0.75	ft
Pop Velocity, Vp (calculated)		1.069526939	mph
Jump		**Breckenridge 2**	
Safe Incoming Transition Velocity Needed, V1 (output)		**34.14029687**	mph

16. Mountain Manager Survey Questionnaire

What does your mountain do to promote terrain park safety?
Would you be open to using a model providing skiers with recommende4d speeds for jumps, if they were proven to be accurate and reliable? Why or why not?
How much does your terrain park affect your insurance?
If there was more education and standards in park building, what impact do you think it would have? Would you support it? Why or why not?
Do you set limitations on your park?
How much oversight/supervision does the mountain maintain over the park management & their maintenance of the park?
Is there anything else?

17. Terrain Park Manager Questionnaire

What is your experience in skiing/snowboarding?
What duties does your job entail?
What is your background in park building?
What methods do you use to ensure that your park is safe?
What are common reasons for people being injured in your park?
Do you know the injury statistics for this year?
What do you think about setting up speed traps in your park to inform riders of their speeds when hitting jumps?
Do you think it will make jumping safer?
Do you think it would help to reduce the amount of injuries?

18. Competitor Questionnaire

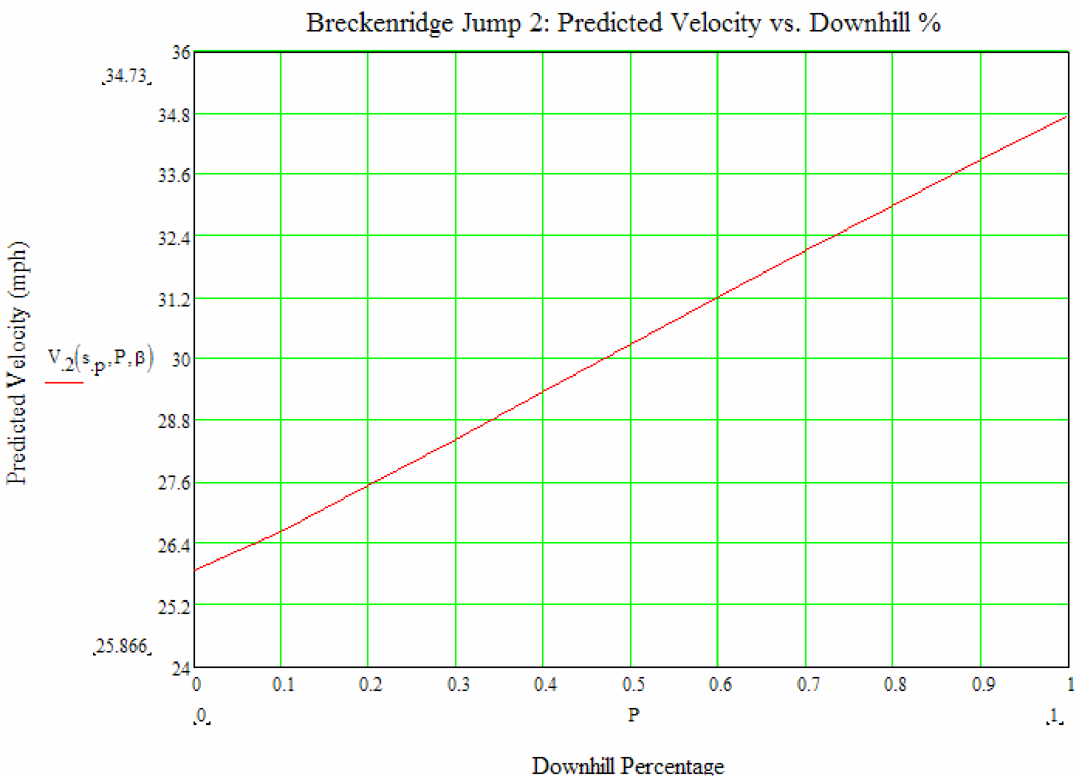
Male:________ Female:______

Age:________

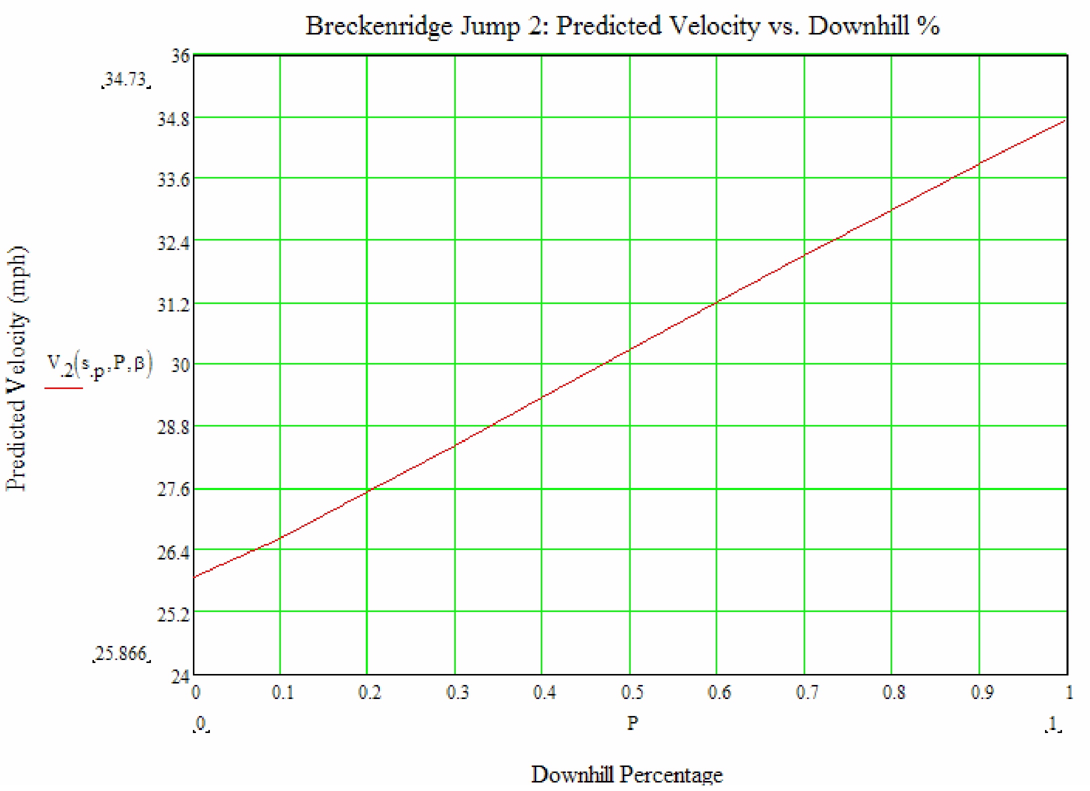
1. How many years have you been hitting jumps for?
2. What qualities do you think make a jump safe?
3. How important is your speed going into a jump?
   (1 is least important, 5 is most important)
4. Do you think there should be more education available for park building & safety precautions?
5. What is your biggest concern when jumping?
   __takeoff __speed __trick __pop __wind
   __landing __gap to landing __jump height
6. If you could pick anything to make jumping safer, what would it be?
7. Do you think knowing a recommended speed for a jump would be useful?

Any other comments you would like to make about park safety and ways in which parks could be safer?

19. Predicted Velocity Breckenridge Jump 2



20. Predicted Velocity Copper Mountain Jump



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