Freestyle Terrain Jump Features Task Group
F27 Committee on Snow Skiing
Definitions and Methods
DRAFT 12/10/2012

I. GENERAL

By convention we view the jump profile as defined below such that the jumper proceeds down the slope and over the jump from upper left to lower right. The x-axis is assumed to be parallel to the horizontal with the positive sense in the direction down the jump or to the right. The y-axis is assumed to be vertical with the positive sense directed upward. The location of the origin is in general arbitrary but choices for an origin are provided where deemed convenient. SI units are used throughout.

II. DEFINITIONS

- *terrain park* -a designated area of a ski resort or other facility containing natural or man-made features such as boxes, rails, slides, and jumps for recreational skiers and snowboarders to ride on or jump.
- *base slope* -the surface within the terrain park upon which the terrain park features are placed or constructed.
- *jump* -a man-made feature within a terrain park intended to cause the rider to become airborne, generally consisting of an approach, transition, takeoff, and landing (see jump elements below).
- *tabletop jump* -a type of jump where the possible landing region consists of a deck and a designated landing slope followed by the runout, with the intention that the rider jump over the deck and land on the designated (approximately constant angle) landing slope before reaching the runout (see Fig. 1).
- *turtle-back jump* -a jump with an upwardly rounded (convex) landing area like the back of a turtle.
- *multiple jump line* -a path through a terrain park intended to enable a rider to access multiple jumps without stopping.
- *pop* -the jumper's action of jumping upward (normal to the takeoff ramp) just prior to takeoff giving the jumper an additional component of velocity normal to the takeoff surface.
- *spin* -the jumper's action of turning and/or spinning his arms at the end of the takeoff giving the jumper a component of angular momentum along his body axis.
- *backseat* -(1) (in jumping) an imbalanced posture of the jumper in the air characterized by being partially inverted or leaning backward in the uphill direction; -(2) (in downhill skiing) a posture of being in a seated position leaning backward with the skier's weight on the heels.
- *jump elements* -the sections or components of a jump which may include the following (see Figure 1):
  - *start* -the designated staging area marking the approximate starting point for a jump or jump line which is intended to allow riders to prepare their equipment prior to executing the jump and which may be used to control the length of the approach and hence the speed at takeoff.
  - *approach* -the downhill portion of the jump after the start used to allow the rider to gain speed.
  - *transition* -the curved region of the jump connecting the downhill approach to the (generally) upwardly sloped takeoff ramp.
  - *takeoff* -the (generally upwardly sloping) part of the jump surface just prior to becoming airborne.
  - *takeoff point* -the last point of the takeoff ramp in sliding contact with the jumper's skis or snowboard just prior to becoming airborne.
  - *maneuver area* -the area above which the rider is intended to be airborne thereby allowing the rider to execute a trick or maneuver.
  - *possible landing area* -the entire area of the slope following the takeoff where a rider could land.

- *designated landing area* -the area of the jump following the takeoff where the rider is intended to land.
- *step-up landing* -a landing area containing some portion that is higher than the takeoff point.
- *run-out* -the region following the end of the designated landing area returning the rider to the base slope.
- *deck* -the generally straight and approximately horizontal section of a tabletop jump which is situated after the takeoff and before the designated landing area.
- *knuckle* -the transition between the deck and the designated landing area on a tabletop jump.
- *bucket* -the transition between the designated landing area and the runout.

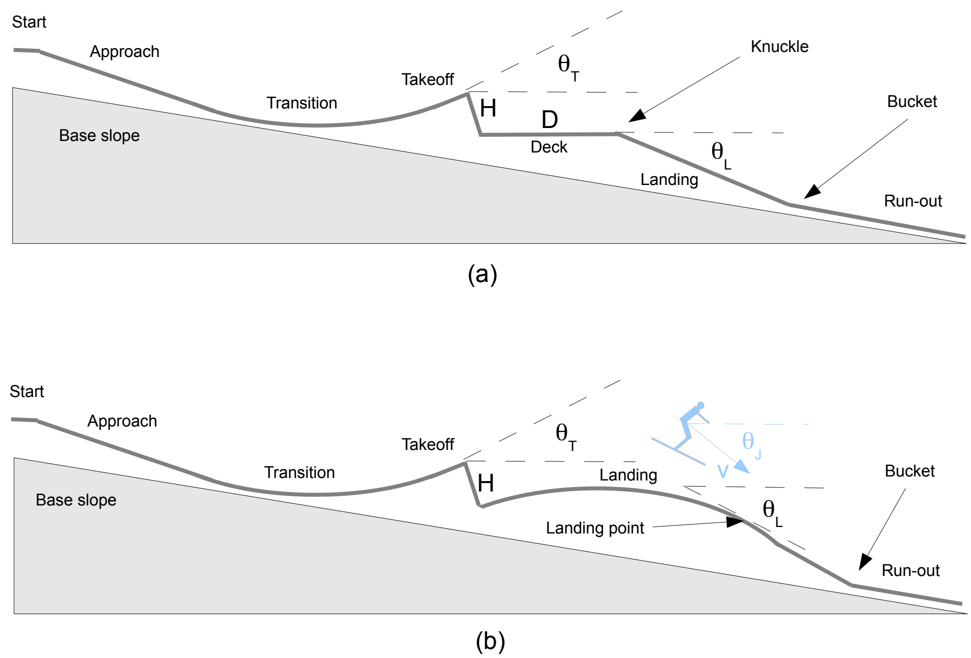

FIG. 1: Example schematics of jump profiles: (a) standard tabletop jump where the landing angle is approximately constant over the designated landing area; (b) turtle-back jump where the entire jump surface between the takeoff point and the runout is a possible (or designated) landing area, and the landing angle changes with the landing point along the surface. Also shown in blue is a hypothetical jumper whose instantaneous velocity is at an angle θ_J with respect to the horizontal.

- *jump parameters* -quantities related to a jump that are either given by the jump designer/builder, measured directly, or calculated from direct measurements. Methods for determining jump parameters are given in the next section.
  - *takeoff angle* (θ_T) -the angle of the takeoff ramp with respect to horizontal at the takeoff point.
  - *takeoff height* (H) -the vertical drop from the takeoff point to the start of the landing surface.
  - *landing angle* (θ_L) -the angle with respect to the horizontal of a line tangent to the landing slope at the point where a jumper lands. A landing area may have different landing angles depending on location.
  - *jump profile* ($y_J(x)$) -the vertical cross section of the jump along a line down the center of the jump that can be mathematically represented by the jump profile function, $y_J(x)$, which gives the vertical height, y_J, of any point on the jump profile as a function of horizontal distance, x.
  - *expected landing point* -the point on the landing where the resort or jump builder expects a typical rider on average to land.

– *expected takeoff speed* -the magnitude of the velocity a jumper at the takeoff point needs so that the flight trajectory will intersect the landing area at the expected landing point, under the assumptions that the takeoff velocity is parallel with the takeoff ramp at the takeoff point and that drag and lift are ignored. A practical method for determining the expected takeoff speed is described in the next section.

– *radius of curvature* (R) -the radius of the osculating circle at any point on the jump profile. Given the jump profile function, $y_J(x)$, the radius of curvature at any point on the jump is given by:

$$R(x) = \frac{1}{y_J''(x)}\sqrt{(1+y_J'(x)^2)^3}, \tag{1}$$

where the primes denote derivatives with respect to x. Note that the radius of curvature will be positive for upwardly curved surfaces and negative for downward curved surfaces. A practical method for determining the radius of curvature for upwardly curved surfaces is described in the next section.

– *equivalent fall height* (h_{eq}) -the vertical height of a fall onto a horizontal surface that would dissipate the kinetic energy associated with the component of the landing velocity normal to the landing surface, $v_\perp$; thus $h = \frac{v_\perp^2}{2g}$. If v_J is the jumper's speed at landing and θ_J is the angle of the jumper's trajectory with respect to the horizontal at landing, then $v_\perp = v_J \sin(\theta_J - \theta_L)$ where θ_L is the landing angle, and,

$$h_{eq} = \frac{v_J^2 \sin^2(\theta_J - \theta_L)}{2g}. \tag{2}$$

A practical method for calculating the equivalent fall height for any landing location using measurements of the takeoff angle, landing angle, and landing coordinates is given in the next section.

III. METHODS

The present section addresses how to measure or calculate values for the parameters defined in the previous section for realistic jumps in the field. For each direct measurement or quantity calculated from direct measurements acceptable tolerances are given. Where needed, the value of the gravitational acceleration constant will be $g = 9.81$ m/s^2.

- *takeoff angle* (θ_T) -the takeoff angle can be obtained using a protractor or inclinometer to measure the angle with respect to the horizontal of a 1 m long rod long placed on the surface at the end of the takeoff along the jump profile. The tolerance in a takeoff angle measurement should be less than 1° as determined by taking at least three measurements that agree to within this tolerance.

- *landing angle* (θ_L) -the landing angle at any location on the landing surface can be obtained using a protractor or digital straight edge to measure the angle with respect to the horizontal of a 1 m long rod or straight edge placed on the landing surface along the jump profile and centered at the landing location. The tolerance in the measurement of the landing angle should be less than 1° as determined by sampling at least three points on the landing surface and taking at least three measurements of each that agree to within this tolerance.

- *landing coordinates* (x_L, y_L) -the landing coordinates relative to the takeoff point for any landing point can be obtained using a tape measure, range finder, or laser distance meter to measure the straight line distance, D, from the end of the takeoff to the landing point and using a protractor or digital level to measure the angle, ϕ, with respect to the horizontal of the straight line from the takeoff point to the landing point using $x_L = D\cos\phi$ and $y_L = -D\sin\phi$. (If line-of-sight from the end of the takeoff to the landing point is not possible, then multiple line-of-sight measurements must be made and these added together to obtain the landing coordinates.) The tolerance in the measurement of the landing coordinates should be less than 2% as determined by sampling at least three landing points and taking at least three measurements of each that agree to within this tolerance. Alternatively, the landing coordinates may be obtained directly from the measured jump profile function as described below.

- *expected takeoff speed* (v_T) -the expected takeoff speed may be approximately calculated according to the drag-free expression:

$$v_T = \frac{x_L}{\cos\theta_T}\sqrt{\frac{g}{2(x_L\tan\theta_T - y_L)}}, \tag{3}$$

where g is the gravitational acceleration constant, θ_T is the measured takeoff angle, and (x_L, y_L) are the given coordinates of the expected landing point in a coordinate system with the origin at the takeoff point. For example, for $\theta_T = 20°$ and $(x_L, y_L) = (20\text{ m}, -8\text{ m})$, one finds $v_T = 12.1$ m/s. If the takeoff angle is measured to within tolerance, then the uncertainty in the expected takeoff speed will be 0.8%. (In this example including drag and lift forces increases the expected takeoff speed for a typical jumper by about 3%.)

- *radius of curvature* (R) -the radius of curvature at a point on upwardly curved (concave) surfaces is calculated by placing a straight rigid rod of length $2\text{m} < L < 3\text{m}$ on the jump surface along the jump profile and centered at the location where the radius of curvature is desired. Since the surface is concave, the center of the rod will be above the jump surface by some measured distance, d. From the values of L and d the radius of curvature is given by

$$R \simeq \frac{4d^2 + L^2}{8d}. \tag{4}$$

The tolerance in the measurements of d and L should be less than 2% as determined by taking at least three measurements that agree to within this tolerance. For example, for $d = 0.10$ m and $L = 3$ m, one finds $R = 11.3$ m. If the measurements in d and L meet their respective tolerances, then for this example the uncertainty in the radius of curvature will be 0.50 m (4.4%). The rod should be rigid to avoid sagging under its own weight which would contribute to a systematic error in the measurement of d. If a rigid rod is not available, then the sag distance must be measured and added to the measurement of d. Alternatively, one can use the jump profile function to obtain the radius of curvature using Eq.1.

- *jump profile function* ($y_J(x)$) -the jump profile function can be obtained by moving down the jump profile from the start while simultaneously measuring the distance traveled, $s^{(i)}$, and the angle of incline (above the horizontal), $\phi^{(i)}$, at least every 0.50 meters, where the index, i, refers to the i^{th} measurement. (Note that for a downhill slope $\phi^{(j)} < 0$.) From this data set a tabulated profile function is calculated from

$$\begin{aligned} y_J^{(i)} &= y_0 + \sum_{j=1}^{i} (s^{(j)} - s^{(j-1)}) \sin(\frac{\phi^{(j)} + \phi^{(j-1)}}{2}) \\ x_J^{(i)} &= x_0 + \sum_{j=1}^{i} (s^{(j)} - s^{(j-1)}) \cos(\frac{\phi^{(j)} + \phi^{(j-1)}}{2}), \end{aligned} \tag{5}$$

where (x_0, y_0) are the coordinates of the start which depend on the location of the origin and $s^{(0)} = \phi^{(0)} = 0$ are initial conditions. Fitting a smooth interpolating function to this tabulated set, $(x_J^{(i)}, y_J^{(i)})$, provides an approximation for the jump profile function. The tolerance in the measurement of the jump profile function should be less than 2% at any point along the jump profile as determined by sampling three points and taking at least three measurements of each that agree to within this tolerance. An alternate method of obtaining the shape of the jump profile $y_J(x)$ is through standard surveying techniques.

In a coordinate system with its origin at the start, one has $x_0 = 0$ and $y_0 = 0$. Jumper trajectories, however, are more conveniently represented in a coordinate system with origin at the takeoff point. For such a coordinate system the starting coordinates are $x_0 = -x_{TO}$ and $y_0 = -y_{TO}$, where (x_{TO}, y_{TO}) are the magnitudes of the horizontal and vertical distances respectively from the start to the takeoff point.

- *equivalent fall height* -the equivalent fall height, h_{eq}, at any landing location is obtained from measurements of the takeoff angle, θ_T, landing angle, θ_L, and the landing coordinates, (x_L, y_L) (in a coordinate system with origin at the takeoff point), using the following approximate drag-free expression:

$$h_{eq} \simeq \frac{(x_L \sin\theta_L \cos\theta_T + \cos\theta_L (x_L \sin\theta_T - 2(x_L \tan\theta_T - y_L)))^2}{4\cos\theta_T (x_L \sin\theta_T - y_L \cos\theta_T)}. \tag{6}$$

For example, for $\theta_T = 20°$, $\theta_L = 30°$, and $(x_L, y_L) = (10\text{ m}, -5\text{ m})$, one finds $h_{eq} = 1.75$ m. For this example, if the measurements of the takeoff angle, landing angle, and landing coordinates meet their respective tolerances, the resulting uncertainty in the measurement of the equivalent fall height will be 0.17 m (9.7%).