



JUMPING HILLS

CONSTRUCTION NORM 2018

Implementing Provisions for Art. 411 of the ICR Ski Jumping

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1. Preliminary Remarks

Jumping hills that are to be homologated by the FIS must be configured in compliance with the requirements of the International Competition Rules (ICR) and the present Construction Standard (Norm). Also for jumping hills that will not be homologated by the FIS, it is advisable to apply the FIS standards.

The geometric elements of a jumping hills and the minimum requirements necessary for the safety of ski jumpers, officials and spectators are specified in the International Competition Rules (ICR) Volume III, Art. 410. They serve hill inspectors and competition management with the assessment and approval of a facility.

The Jumping Committee created this standard for the planning of a new installation or for the conversion of an existing installation. It is aimed at engineers and architects who are responsible for project planning. In contrast to the last issue from 2012, the detailed description of mathematical operations has been omitted. They are presented in the associated Excel program JUMP-3.5 (Program).

The basis for the standards work is extensive investigations into the biomechanical and physical processes during a ski jump. Particularly significant are the analysis of trajectory recordings and the detection of forces occurring in the air. The jump committee is updated through periodically scheduled surveys on the progress of ski jumpers and changes in the equipment over time.

Dr. Hans-Heini Gasser, a member of the Jumping Hills subcommittee, has developed the Excel program JUMP-3.5 through computer simulation of the trajectory and analysis of the biomechanical processes on the inrun, take-off and landing. In the paper "*Grundlagen der Auslegung des Längsprofils einer Skisprungschanze*" (Basics of a Ski Jumping Hill's longitudinal profile) 2018, he describes the geometric and physical fundamentals, as well as the safety aspects. This can be downloaded on the FIS [Website](#).

The computer program leaves a number of parameters open for modification so that it is possible to optimally adapt a longitudinal profile to the given terrain profile.

The program does not yet contain updated results on the influence of air pressure when jumping on a flying hill, so for the time being the program cannot be used for ski flying hills.

The Microsoft Excel program, JUMP-3.5, can be ordered by prepayment of CHF 1'500 from the International Ski Federation, CH-3653 Oberhofen,
e-Mail: friedrich@fisski.com

2. Geometric Elements of a Ski Jumping Hill

See Illustration 1

Inrun:

A_s	Highest start gate with a snow track
A_e	Highest start gate with an ice track
B	Lowest start gate
E_1	Beginning of the transition curve
E_2	End of the transition curve; beginning of the table
T	Takeoff
e_{1s}	Length of the inrun from the highest start A_s to T with a snow track
e_{1e}	Length of the inrun from the highest start A_e to T with an ice track
e_2	Length of the inrun from the lowest start B to T
e_s	Length of the inrun from the lowest to the highest start
t	Length of the table
γ	Angle of the straight part of the inrun
α	Angle of the table
r_1	Radius of the transition curve in E_2

Landing Profile:

T	Takeoff (= base coordinates)
s	Height of the table
P	Beginning of the landing area
K	Construction point
L	End of the landing area
U	End of the transition curve to the outrun
HS	Nominal Size (Hill Size) of the hill as the distance between the takeoff and the end of the landing area L
w	Distance between the takeoff and the construction point K
h	Difference in height between the takeoff and K (K_z)
n	Horizontal distance between the takeoff and K (K_x)
U_z	Difference in Height between the takeoff and the lowest point U ($-U_z$)
l_1	Length of the curve P-K
l_2	Length of the curve K-L
l	Length of the curve of the landing area P-L
a	Length of the outrun after U
β_0	Angle of the tangent of the knoll profile at the base of the takeoff
β_P	Angle of the tangent at P
β	Angle of the tangent at K
β_L	Angle of the tangent at L
r_L	Radius of the circular landing area
r_{2L}	Radius of the transition curve from L to U at L
r_2	Radius of the transition curve from L to U at U
b_1	Prepared width of the inrun
b_2	Width of the knoll at the base of the takeoff
b_K	Width at K
b_U	Width at U

Judge Tower:

- d Horizontal distance between the takeoff and the projected middle of the lowest judge cabin along the jumping hill axis line
- q Horizontal distance between the front of the judge tower and the jumping hill axis line

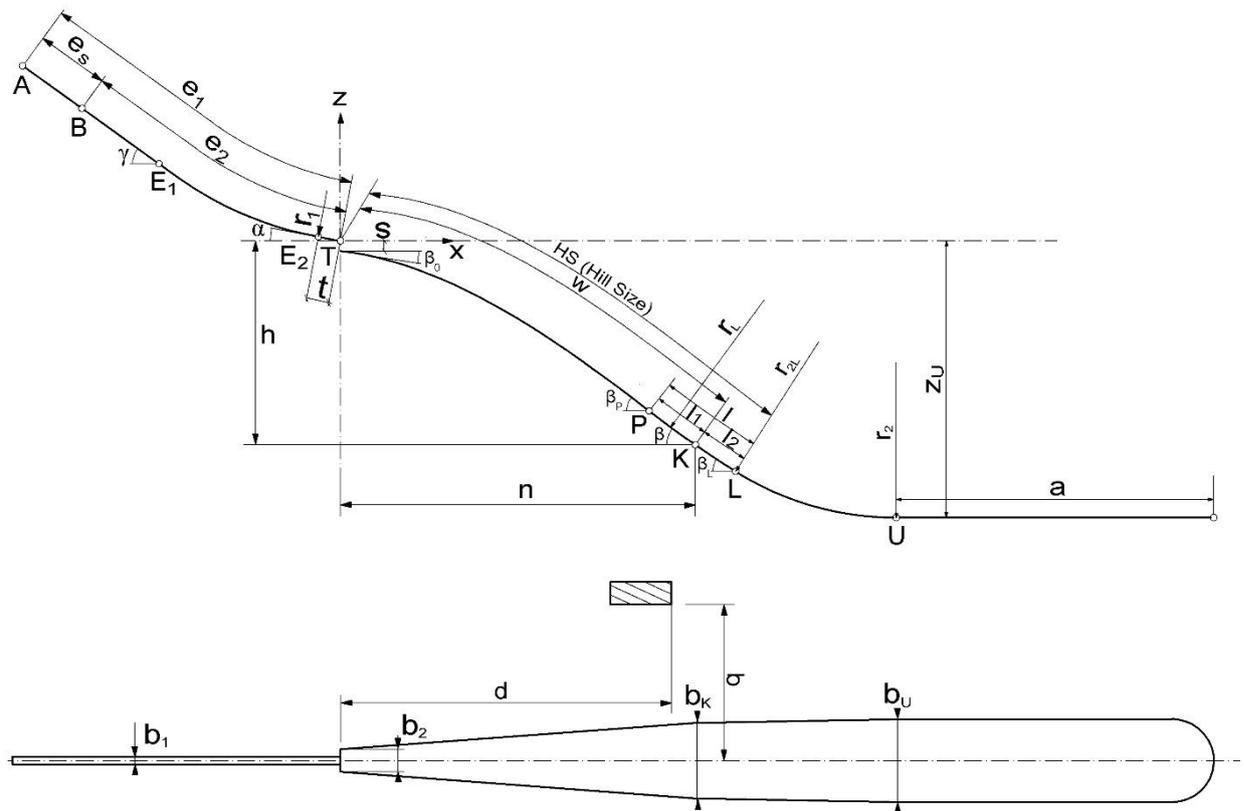


Figure 1. Ground Plan and Longitudinal Profile

In the case of plastic covered jumps the required snow cover for plastic hills is 35 cm above the mats. If the inrun tracks are the same in summer as in winter, the difference in profile height must be taken into account. The smaller the hill, the greater the impact.

3. Classification of Jumping Hills

The size of a jumping hill is determined by the distance at L (HS). The following terms apply:

Designation	HS	Associated Distance w
Small Hills	49 m and under	44 m and under
Middle Hills	50 m to 84 m	45 m to 75 m
Normal Hills	85 m to 109 m	76 m to 98 m
Large Hills	110 m to 145 m	99 m to 130 m
Flying Hills	185 m and over	166 m and over

Large hills with a difference in height between the lowest point on the outrun and the takeoff of more than 88 m are not homologated by the FIS (ICR Article 411.1). If a normal and a large hill are built in the same place, the difference in HS must be at least 25 meters.

4. Components of a Hill

4.1 Inrun

The inrun consists of a straight portion with an inclination γ , followed by a clothoid-like transitional curve with an end radius of r_1 and a straight table with length t and inclination α .

e_1 is the inrun length from the highest start A to T (Figure 1), that is required for a jumper to reach the K point with a tailwind of 3 m/s. There should be a distinction between an ice track and a snow track.

e_2 is the inrun length from the lowest start B to T. This inrun length ensures that a good jumper does not jump past L with a headwind of 4 m/s and a fast track.

The inrun length is the entire section of the profile from the point on the track perpendicular to the start bar (Happle-Bar) to the takeoff edge.

$e_s = e_1 - e_2$ Start Area. The start gates in e_s must be arranged at equal intervals, where the difference in height between two starts may not be greater than 0.40 m. They must also be numbered consecutively, beginning with the number 1 at the lowest start.

The following applies for the table angle α :

$$w/30 + 6.9 \leq \alpha^\circ \leq w/30 + 7.9.$$

The program calculates with $\alpha = w/30 + 7.4$. A larger α means a lower height of the flight curve, a smaller α means a higher height of the flight curve. On a large hill with HS 145, the use of a α variance of -0.5° to $+0.5^\circ$ translates to heights from 3.3 m to 3.7 m.

4.2 Landing Profile

The landing profile consists of the **knoll**, **landing area**, **transition** and **outrun** sections. The takeoff position along the jump axis is the first thing to be estimated from the terrain section. The steepness of the existing terrain results in a certain h/n ratio with the following restriction

$$w/800 + 0.400 \leq h/n \leq w/1000 + 0.480.$$

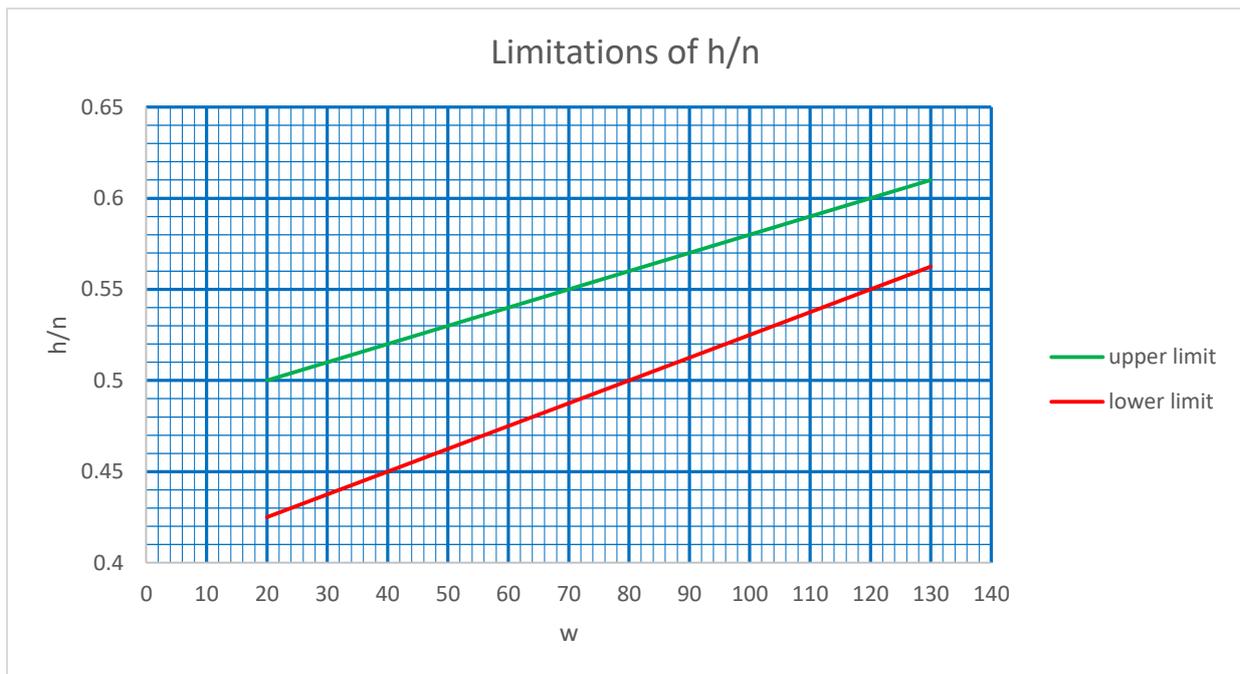


Figure 2. Diagram of the limitation of h/n for K points from 20 m to 130 m

The knoll should be adapted in a manner that the highest point of the flight trajectory of the jumper is reached about halfway through. A cubic parabola will resolve this challenge nicely.

The section from P to L is designated the **landing area**. It should lead to distances that clearly reflect the jumping skill of the athletes and therefore allow for fair rankings. An upward open circular arc, which is a counterpart to the trajectory's downward open arc is used for this purpose. The jumping skill required increases steadily as the distance increases.

The **transition** is a parabola. It allows the radii r_{2L} and r_2 to be freely selectable at points L and U.

The **outrun** in its design should be adapted to the terrain conditions, but its length must be sufficient to allow the rate of speed to slow to a stop.

5. Definition of the Compensation Factors

In order to be able to change the start gate during a competition round, an understanding of the associated effect on distance is required. Increasing wind can be a reason for a gate change as well. These two factors depend on the geometry of the hill and must therefore be determined for each jumping hill. Both are to be calculated for the "winner's distance" $w_s = (w+HS)/2$ and they are defined as follows:

Gate Change (adjustment of the inrun length): Determine the inrun length e_s that results in distance w_s with no wind. Then determine the distance w , resulting from an inrun length 3 m shorter ($e_s - 3$) under calm conditions. The gate factor is one third of the difference between these two distances.

Headwind: Determine the distance that is achieved with inrun length e_s and wind of +3m/s. The wind factor is one third of the difference between this distance and w_s .

Tailwind: Determine the distance that is achieved with inrun length e_s and wind of -3m/s. The wind factor is one third of the difference between this distance and w_s .

The factors are multiplied by the points per meter value defined for the hill type.

6. Specifications that Underlie the Excel Program JUMP-3.5

6.1 Formulas and Units of Measure

In all formulas, lengths and distances must be in meters, speeds in meters per second and angles in degrees (360°). Most coefficients have a dimension (time, acceleration, etc.). These are omitted to improve readability.

Common algebraic syntax and the usual priority rules are used for the representation of mathematical expressions.

6.2 Physical Laws

Gliding on the inrun and landing as well as the flight is described mathematically by differential equations, which the program solves with the Runge-Kutta algorithm.

Dry friction is assumed for the sliding phases, with a friction angle of 1° for ice and ceramic tracks and 3° for naturally cooled snow tracks.

Air resistance and lift coefficients are periodically checked and updated at ski jumping competitions. The actual values can be seen in the program in cells N65, N66 and AF939 for the sliding phases and in columns Q to Z rows 2 and beyond for the flight phase. The values representing the air forces in flight are the coefficients of a polynomial function that are dependent on the angle of the hill and are valid for the mean air density at sea level.

Wind influence is considered under the simplifying assumption that it remains constant for the entire distance of the flight.

6.3 Biomechanical Limits

Speed and direction from the takeoff are the initial conditions of the trajectory. The direction is determined by the inclination of the table α and the velocity component v_{\perp} from the jumping motion. The value v_{\perp} is subject to change and differs according to the class of the jumpers and the type of hill. The currently effective values can be viewed in the program in cells AA3 and beyond.

When landing, the jumper experiences an impact that can be quantified with the equivalent landing height (e.LH). The impact is compared to the impact of dropping from the e.LH onto a horizontal landing surface. When landing at the K-point this impact should be gentle (comfortable landing height); a limit is reached at the L-point beyond which a safe landing is no longer guaranteed. Based on many years of experience and athlete trials in 2016, the e.LH was determined. The values are stored in the cells AB3/AC3 and following.

Jumpers experience a centrifugal force in the transition areas of the inrun and outrun. This may not exceed 70% of the jumper's weight at point E_2 and 80% of the jumper's weight between L and U.

6.4 Geometric Parameters and Directional & Limit Values

The inrun angle γ may not exceed 37° , but it is recommended that it not exceed 35° . For jumping hills where $w \geq 90$, γ should be at least 30° and for jumping hills where $w < 90$ at least 25° . For beginners' hills where $w < 30$, γ should not exceed 32° .

The distance of a point of the landing profile from the takeoff edge T is defined in ICR Art. 415.1. The program calculates it with the approximation formula

$$w = 1.005*[T-P],$$

where [T-P] means the oblique distance of T and P.

The initial parameters for a jumping hill are the distance w to the point K, and the steepness expressed by the ratio h/n (see Figure 1).

The two variables w and h/n are for the most part freely selectable. However, decades of experience with jumping hills of all sizes has limited this freedom. See Section 4.2 and Figure 2. From these two parameters, the position of the K point can be calculated. With the selection of a table angle α , the jump speed v_0 , at which the jumper reaches the K point in calm weather, is also determined. The profile angle β is determined by the e.LH permitted at the K point.

The distance to L is HS (Hill-Size). It is the limit at which a good jumper can still safely stand and follows the relationship

$$HS = w/0.9.$$

At the P point, the beginning of the landing zone, the curvature of the longitudinal profile changes direction (inflection point). The slope of the landing hill reaches its maximum at P. It is

$$\beta_P = \beta + 0.5*\alpha - 2.5.$$

With that, the highest permissible angle is $\beta_P = 37^\circ$.

Furthermore, $\beta_0 = \beta_P/6$.

The coordinates of the L point are calculated by the program according to the specification that its distance is HS and that a jump with its associated landing speed at L falls on a profile inclination of β_L , which corresponds to the e.LH for the point L. These two conditions allow for the determination of the position of L, the slope β_L and its radius r_L .

The U point is obtained via a parabolic arc from L, with an angle of β_L , to U, with an angle of 0° . For normal and smaller hills the radii of curvature should be

$$r_{2L} = r_L,$$

where r_{2L} and r_2 ensure that the centrifugal force on the jumper between L and U does not exceed 80% of his weight. Pressure $\leq 1.8g$.

With large hills the limit

$$U_z \geq -88 \text{ m}$$

must also be adhered to. This limitation, together with the pressure limit of 1.8 g in the transition to the outrun, means that large hills reach their maximum distance at $w \approx 130$ m or $HS \approx 145$ m.

The outrun after point U is as a rule a flat surface with a descending plane indicating positive δ values and an ascending plane negative δ values.

The program calculates the length of 'a' with the following steps:

1. The jumper travels after U for one second with a mean deceleration force of $0.003*v^2$.
2. He continues with an average deceleration of 4.8 m/s^2 and an acceleration or deceleration, when δ is not 0°) until a speed of 18 m/s is reached.
3. At 18 m/s, the jumper performs a side (hockey) stop. For this action he still requires 20 m.
4. $a \geq 45$ m.

For summer use with a grass outrun 'a' should be increased by 15 m.

The program calculates a according to these specifications. If the outrun follows as a curved (non-flat) surface, calculate the outrun length in the phases described by a numerical algorithm.

The position of the judge tower (see Figure 1) is restricted by the limits

$$d = 0.60w \text{ to } 0.80w$$

$$q = 0.25w \text{ to } 0.50w.$$

The height of the judge cabins should be determined in such a way that the judges' view of the jumper is guaranteed in his flight from the edge of the takeoff to at least the fall line. In assessing this, crash barriers, slope edges and any mechanical climbing aids between the judge tower and the jumping hill need to be considered.

Further guidelines and limits are listed in ICR Art. 411.4 and 411.5.

7. Precision of the Parameters in the Hill Certificate

Curvature Radii	to the nearest Meter
Lengths	to the cm
Angles	to one tenth of a degree
Velocities	to two decimal places
h/n	to three decimal places