

Standards for the Construction of

Jumping Hills - 2012

Application to Rule 411 of ICR Volume III

(June 2012)

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1. Opening comments

Ski jumping hills, which are to be homologated by FIS, need to be constructed to the actual FIS standards. It is also recommended, that even though a hill may not be FIS Homologated, it should be built to the current FIS standards.

In the FIS International Ski Competition Rules (ICR), Volume III, Rule 411, the geometric elements of a ski jumping hill are defined and minimal construction requirements are described. These are necessary for the safety of the Ski Jumper, the Officials and the Spectators. These rules serve the Ski Jump Inspectors to see that these minimum requirements are met and grant admission/licence for the hill to be used

For the architects or the engineers who are planning, designing a new Ski Jump or reconstructing an existing hill, the Jumping Committee has created present construction standards. Rule 411 from ICR, Volume III is included into these standards.

Presented charts and formulas are based on extensive studies of biomechanical and physical actions of the World Cup skijumpers during December 2006 on the large hill ‚Titlis‘ in Engelberg, Switzerland. The flight trajectory recordings, its analysis and the identification of the air pressure values were carried out by the Institute for Biomechanics of the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland under the direction of Dr. Jachen Denoth and Dr. Hans Gerber. Dr. Hans Heini Gasser, member of the Ski Jumping Hills Sub-Committee, has prepared the geometric elements of a ski jumping hill by means of computer simulation of the flight trajectory and after the specification of the take off angle and the landing angle by the Sub-Committee for jumping hills. He has derived various construction specifications/calculation diagrams, which are to be used as a basis for a construction.

The geometric and physical bases as well as the safety aspects used during simulation and evaluation Gasser has documented in paper. This can be downloaded from the FIS web page: www.fis-ski.com/data/document/grundlagen-fur-die-auslegung.pdf

Despite all the scientific analysis, some of the facts are based on the praxis and come from the experience. In this sense considered, the present rules are guidelines. However, it must be warned, not to vary the individual results to strong. The continuation of the calculation could deliver falsified values, because you must understand, that through simplification of the formulas, for example linearising, they would provide accurate results only in a relatively limited area.

The existing bases contain no supplements to the rule 412 and subsequent rules. It especially does not apply to ski flying.

Important:

There is a new specification of the in-run length from the upper starting place to the edge of the take-off (e1) and from the lowest starting place to the edge of the take-off (e2). For the calculation of the length of the in-run there is the excel program "JUMP-2 2.0", that you can order at the FIS Office (FIS Nordic Office, Blochstrasse 2, CH-3653 Oberhofen, e-mail: friedrich@fisski.com). This program will be updated periodically.

Included into this program is progress in ski jumping (technical and material) that we have followed since 2006. This means, we can no longer use the old formulas for e and es, neither the old "JUMP-2 1.4" computer program for the in-run length calculation.

2. Geometric elements of a ski jumping hill

See Figure 1

In-run:

A	Highest start place
B	Lowest start place
E_1	Beginning of the transition curve
E_2	End of the transition curve. Beginning of the take-off table
T	Edge of the take-off table
e_1	length of the in-run from the upper starting place A to T
e_2	length of the in-run from the lowest starting place B (No. 1) to T
e_s	Length of starting places A until B
t	Length of the take-off table
γ	Gradient of the straight part of the in-run
α	Gradient of the take-off table
r_1	Radius at the end of the transition curve before the take-off table E_2

Profile of the landing area:

T	Edge of the take-off table
s	Height of the take-off table
P	Beginning of the landing area
K	Construction point
L	End of the landing area
U	End of the transition curve towards the out-run
HS:	Hill size - distance from the edge of the take-off to the end of the landing area L
w	Distance between edge of the take-off and the construction point K
h	Height difference from the edge of take-off to the K point
n	Horizontal distance from the edge of take-off and K point
z_U	Height difference between the edge of take-off and the lowest point U
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 out-run
β_0	Tangent angle of the landing hill at the base of the take-off
β_P	Tangent angle at P point
β	Tangent angle at K point
β_L	Tangent angle at L
r_L	Radius of the landing area curve at P-L
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 in-run
b_2	Width of the landing area at the base of the take-off
b_K	Width at K
b_U	Width at U

Judges tower:

- d Horizontal distance from the edge of the take-off and the middle of the lowest judges window
- q Horizontal distance between the front side of the Judges tower and the center line of the landing hill

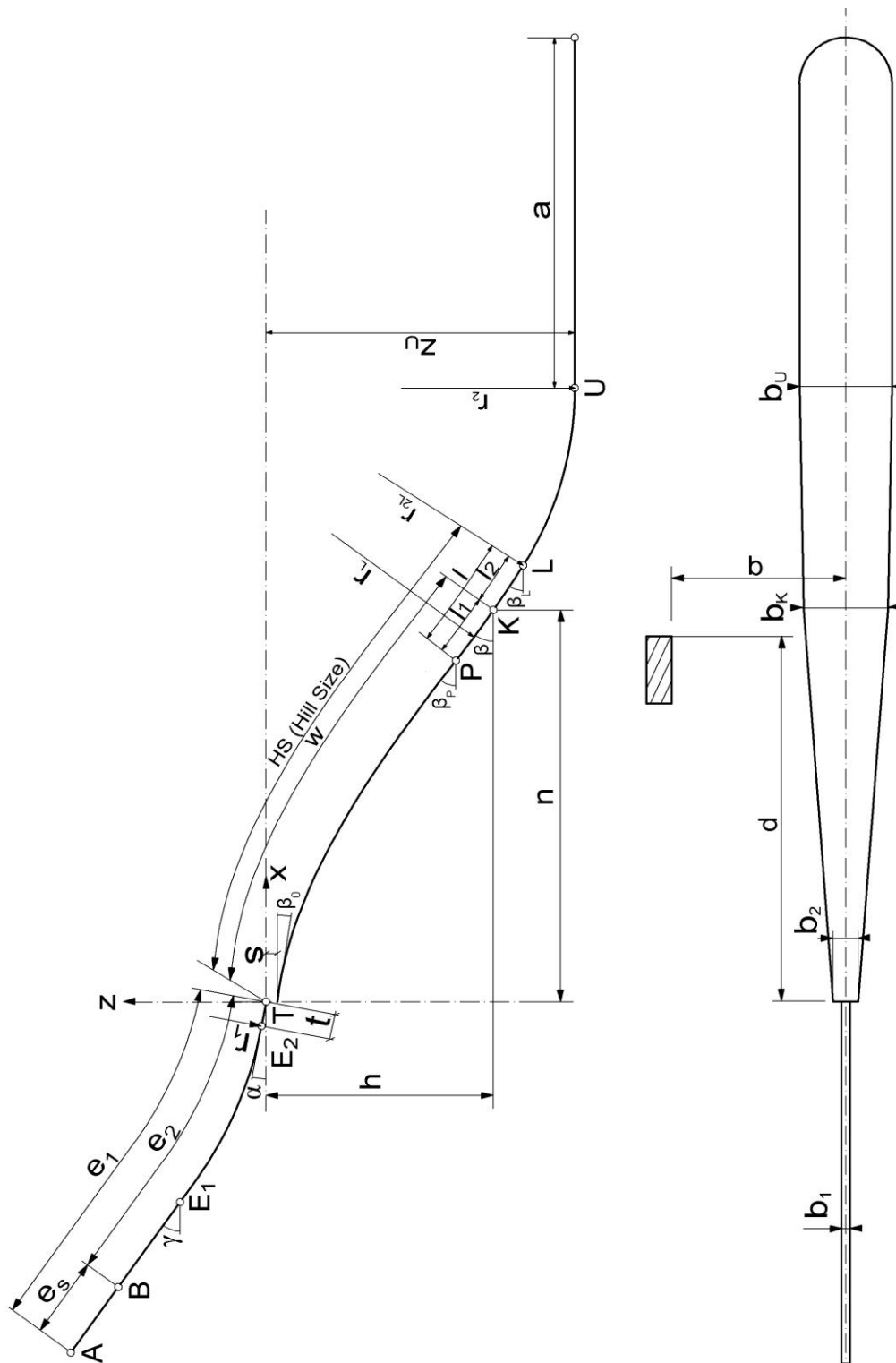


Fig. 1

3. Classification of the ski jumping hills

The size of a ski jumping hill is named after the distance to the L-point (HS). Apply the following description.

Description	Hill size (HS)	Distance to K point (w)
Small hills	49 m and smaller	44 and smaller
Medium hills	50 m to 84 m	45 m to 74 m
Normal hills	85 m to 109 m	75 m to 99 m
Large hills	110 m and larger	100 m and larger
Flying hills	185 m and larger	170 m and larger

Large hills for which the height difference between the lowest point in the out-run and the edge of the take-off exceeds 88 m will not be homologated by the FIS.

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

4. Formulas and diagrams

All formulas require lengths in meter, speeds in meters per second and angles in old degree ($^{\circ}360$). Most coefficients have a dimension (time, acceleration etc). To improve the readability they are omitted.

In the presentation of the mathematical expressions, common algebraic syntax with the usual priority rules applied are used.

Exit size in the formulas for the geometric elements of a jumping hill is w. The HS distance, introduced in the 2004 ICR edition, $HS = w + l_2$ leads to the approximate formula

$$w = 0.885 \cdot HS + 1.5$$

For a desired HS, you must first calculate the distance w. That l_2 , resulting from the further profile calculation, is to be added to w in order to receive HS. Any deviation to the required HS requires a new calculation with the corresponding correction of w.

4.1 In-run profile

The in-run profile consists of one straight formed part with the gradient γ , a subsequent, klothoide-like transition curve with the end radius r_1 and the the straight take-off table, with his gradient α and his length t.

v_0 is the component of the jump speed at the take-off, which is parallel to the gradient of the take-off table, which the best jumpers need to reach the K point of the ski jump hill in calm winds. This can be derived from the diagrams 4-11. More details in chapter 4.2.

e_1 is the length of the in-run from the upper starting place A to T (fig. 1), that a jumper must have to reach the K-point with 3 m/s tail wind and with a fast in-run track or ice track with a snow friction angle of 1^0 . If there is no in-run cooling system planned, the snow friction must be calculated with 3^0 .

e_2 is the length of the in-run from the lowest starting place B (No. 1) to T. This in-run length shall guarantee that the best jumpers will not jump over the L-point if there are 4 m/s head wind conditions and at the same time there is also ice track on the in-run.

Formulas, we use for the calculation of the in-run length are:

$$e_1 = 92.3 - 1.517 \cdot \gamma + 0.426 \cdot HS$$

$$e_2 = 67.3 - 0.944 \cdot \gamma + 0.331 \cdot HS$$

$e_s = e_1 - e_2$ is starting area. Distances between the starting places must be the same.

Excel program JUMP-2 2.0, mentioned on Page 4 in section 2, calculates the in-run length considering all the hill parameters and the overall progress and development in ski jumping. This program calculates e_1 also for the natural in-run track, if there is no cooling system (friction angle 3^0).

Front edge of the first starting bar (No. 1) must be positioned vertically to the point B. The height of the starting bar shall be adjustable for the summer and winter track and also for different height of the jumpers.

$$r_1 = 0.14(v_0 + 0,95)^2$$

$$t = 0.25(v_0 + 0,95)$$

In-run speed increased by 0,95 m/s will be reached when starting from the upper starting place.

The in-run inclination γ may at most be 37^0 . It is recommended that γ not exceed 35^0 . for ski jumping hills, where $w > 90$, γ should be at least 30^0 and for ski jumping hills, where $w < 90$, the minimum for γ should be at least 25^0 . For beginner ski jumping hills, where $w < 30$, γ should not be greater than 32^0 .

The take-off table inclination α depends on the geometric data of the landing hill profile (see next chapter).

The transition curve is to be constructed in accordance with Figure 2 and the accompanying formulas.

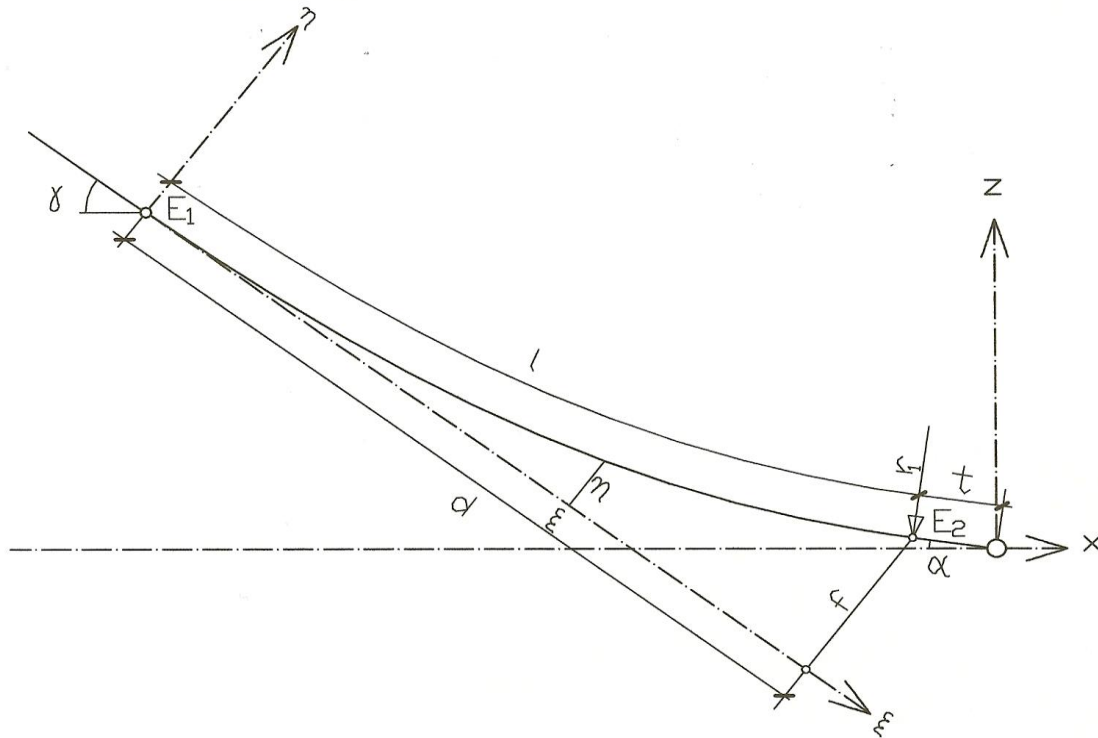


Fig. 2: Cubical parable as a transition curve in the in-run

If we use the letters ξ and η for the coordinates which are twisted around the inrun gradient γ , we get the function

$$\eta = C \cdot \xi^3$$

Given are the geometric data of the table t and α , the curve radius r_1 at the end point E_2 and the inclination γ of the acceleration section. This yields in turn

$$d = 2 \cdot r_1 \cdot \sin(\gamma - \alpha) \cdot \cos^2(\gamma - \alpha)$$

$$C = \operatorname{tg}(\gamma - \alpha) / 3d^2$$

$$f = \operatorname{tg}(\gamma - \alpha) \cdot d / 3$$

The transition curve $l = d \cdot [1 + 0,1 \cdot \operatorname{tg}^2(\gamma - \alpha)]$

Start and end point of the transition curve E_1 and E_2 are:

$$\vec{E}_1 = [- (t \cdot \cos \alpha + f \cdot \sin \gamma + d \cdot \cos \gamma); (t \cdot \sin \alpha - f \cdot \cos \gamma + d \cdot \sin \gamma)]$$

$$\vec{E}_2 = [- t \cdot \cos \alpha; t \cdot \sin \alpha].$$

The longitudinal profile of the transition curve can be calculated in the twisted ξ ; η coordinate system with the function $\eta = C * \xi^3$. With a programmable calculator, the transition curve can be simply calculated also in the x-z coordinate system. The value x belonging to a given value ξ must first be calculated from an equation of the third degree. Use these values for this:

$$P = \text{ctg}\gamma/3/C;$$

$$Q = (x + t*\cos\alpha + f*\sin\gamma + d*\cos\gamma)/2/C/\sin\gamma.$$

Therefore one receives $\xi = [(Q^2 + P^3)^{1/2} + Q]^{1/3} - [(Q^2 + P^3)^{1/2} - Q]^{1/3}$

and in the end $z = t*\sin\alpha - f*\cos\gamma + d*\sin\gamma - \xi*\sin\gamma + C*\xi^3*\cos\gamma.$

4.2 Landing hill profile

The landing hill profile consists of the sections **knoll**, **landing area**, **transition** and **out-run**. In a ski jumping hill project, w is usually set as the nominal size of the jumping hill. Out of the terrain cut through the planned jumping hill axis, the placement of the edge of the take-off table is to be estimated first of all. Out of the steepness of the available terrain, an h/n ratio certainly recommends itself. Both values w and h/n can not be chosen independent from one another. The recommended range limitations are shown in Figure 3 - 10 diagrams.

The areas are different for the different take-off table inclinations. From the comparison of the charts, the take-off table inclination is selected in that the desirable value pair w and h/n are in the allowed range. Therewith also the third parameter α (Table inclination) is given. From the corresponding chart, the in-run speed v_0 as well as the profile angle of inclination β at the K point can be derived (linear interpolation).

Diagrams in Figure 3 – 10 are based on the evaluations of the flying trajectory measurements from the World Cup competition in Engelberg 2006. Since then we could see important progress in ski jumping which is presented as a reduction of the in-run speed needed for the same distance. This increase in performance is presented as $v_{\text{alt}}/v_{\text{neu}}$. There might be also some difference in the flight trajectory, but it is a minor one and there is no need to change the geometry of the landing area of the jumping hill. We are on the safe side with the existing parameters for the transition curve and outrun. There is also no need to change the geometry of the in-run track because of the progress in ski jumping, with an exception of the shortest in-run length e_2 . Because of the lower in-run speed of the top class ski jumpers the lowest starting gate must be positioned lower to guarantee, they will not jump over L-point.

This increased performance of the jumpers must be entered into excel program “JUMP-2 2.0” to get the right in-run length. For the season 2012/2013 this was:

$$v_{\text{alt}}/v_{\text{neu}} = 1.06$$

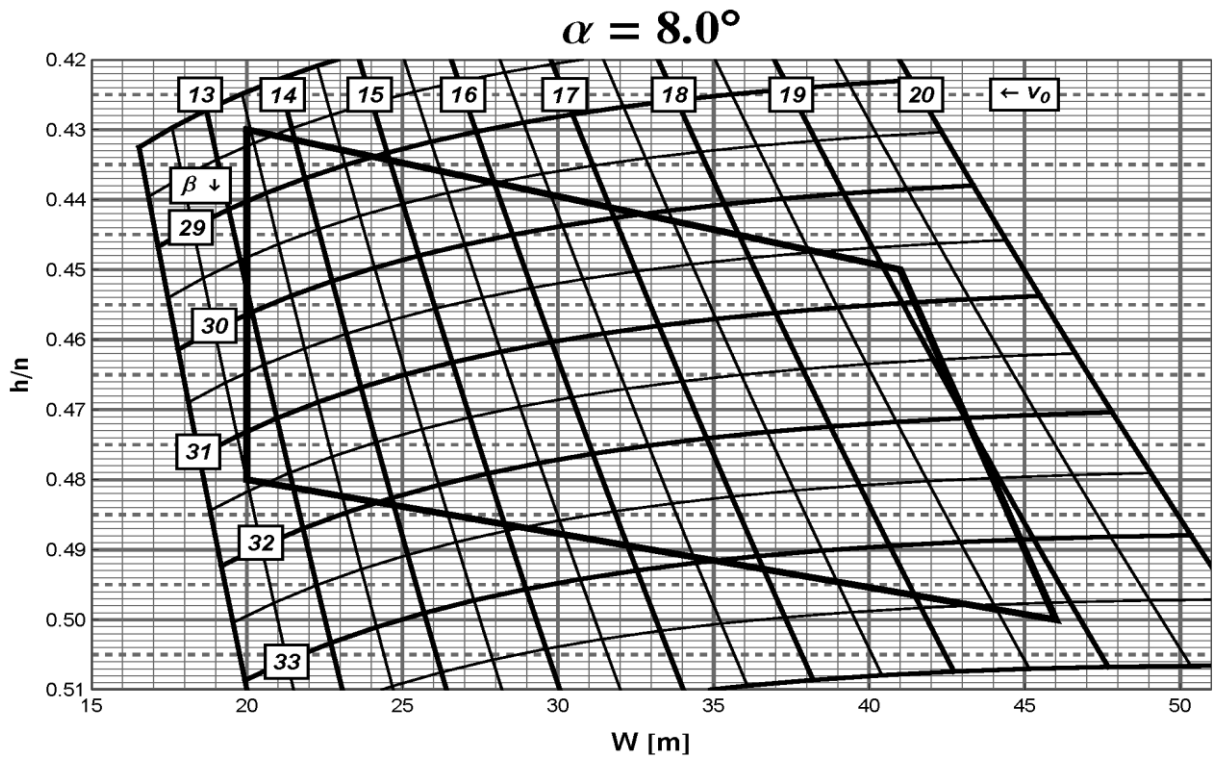


Fig. 3

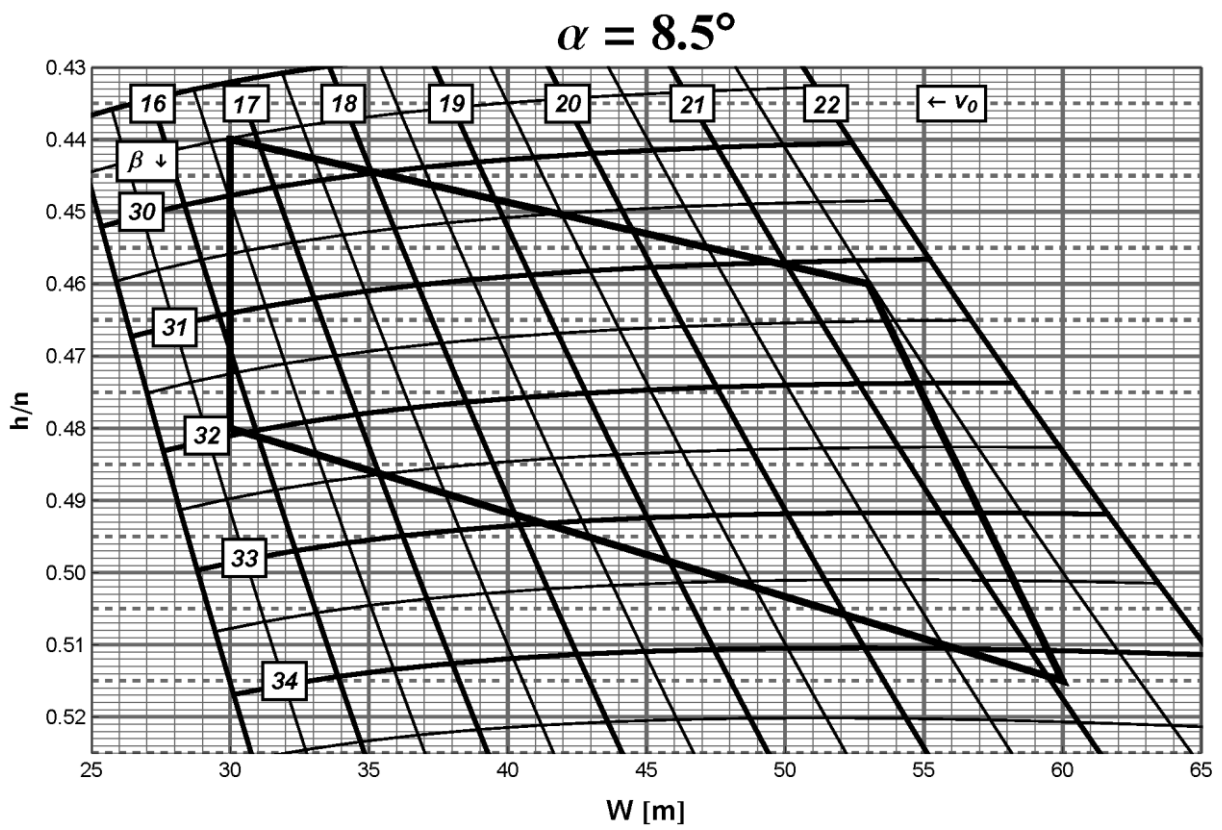


Fig. 4

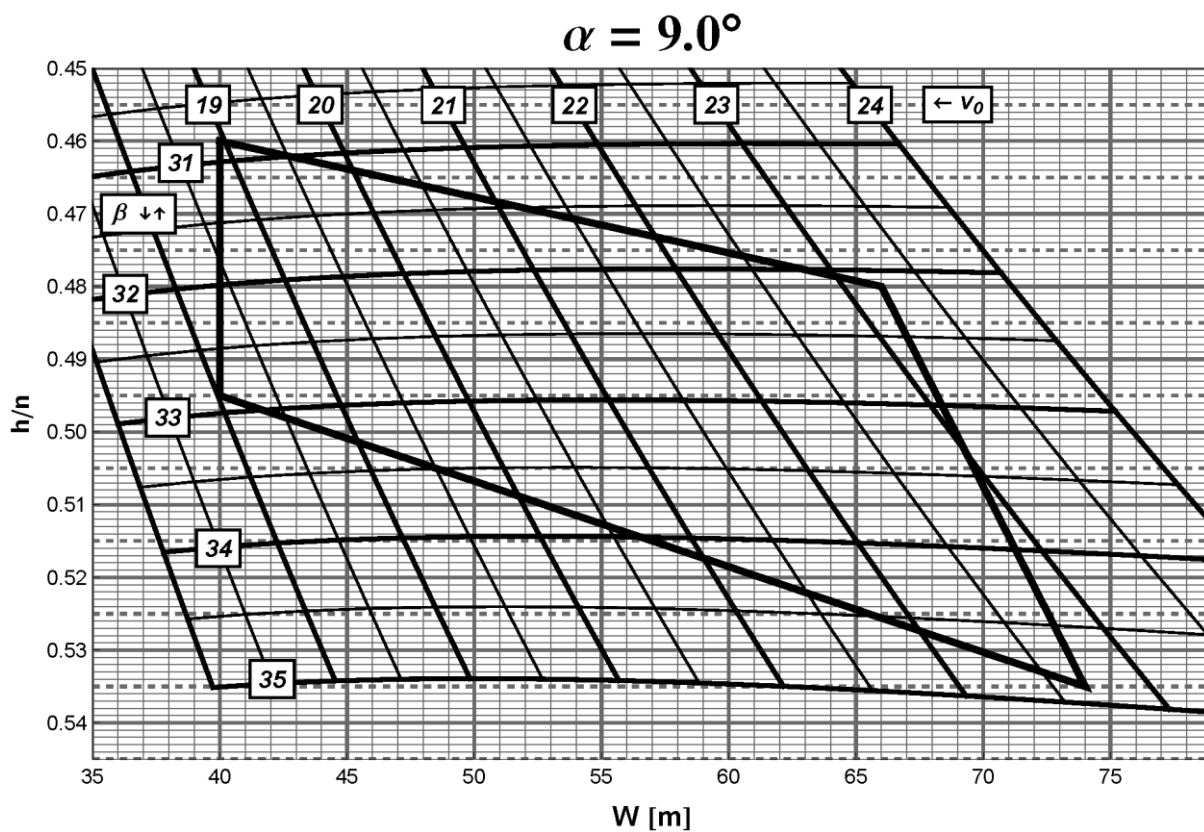


Fig. 5

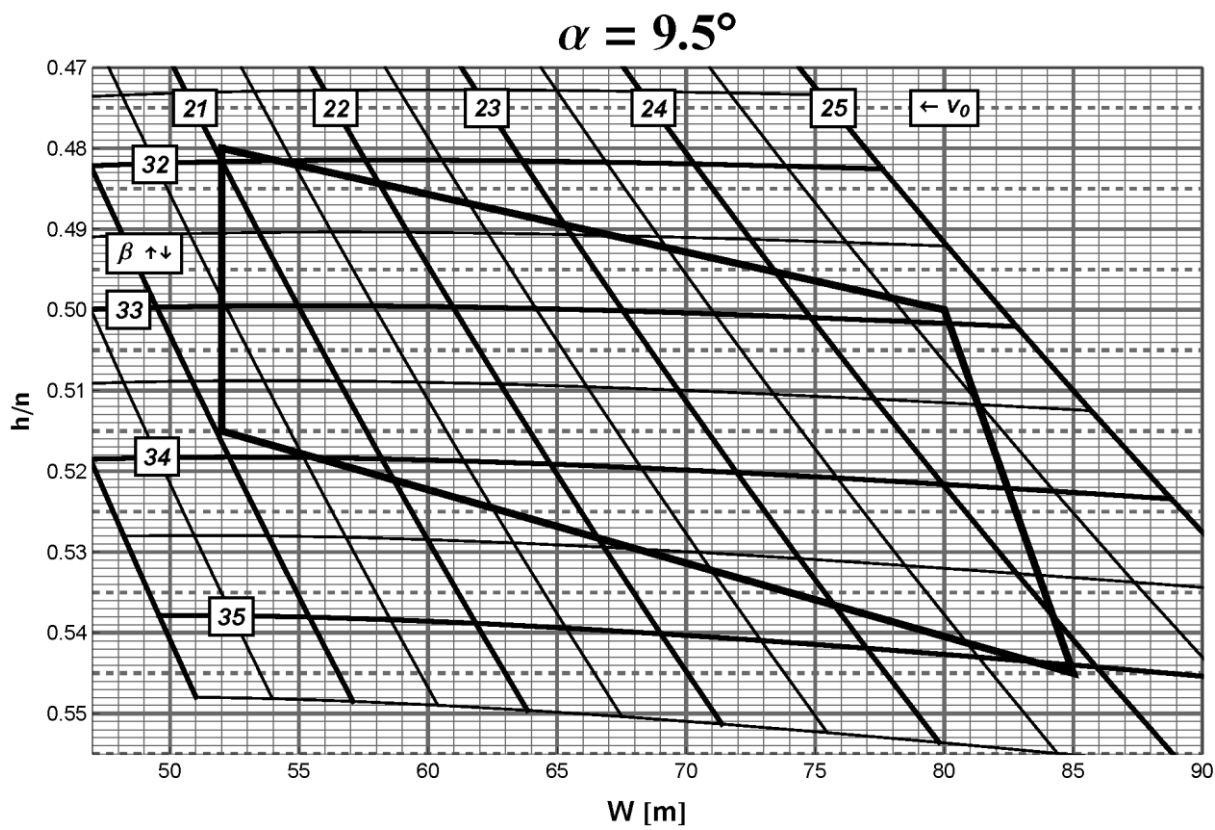


Fig. 6

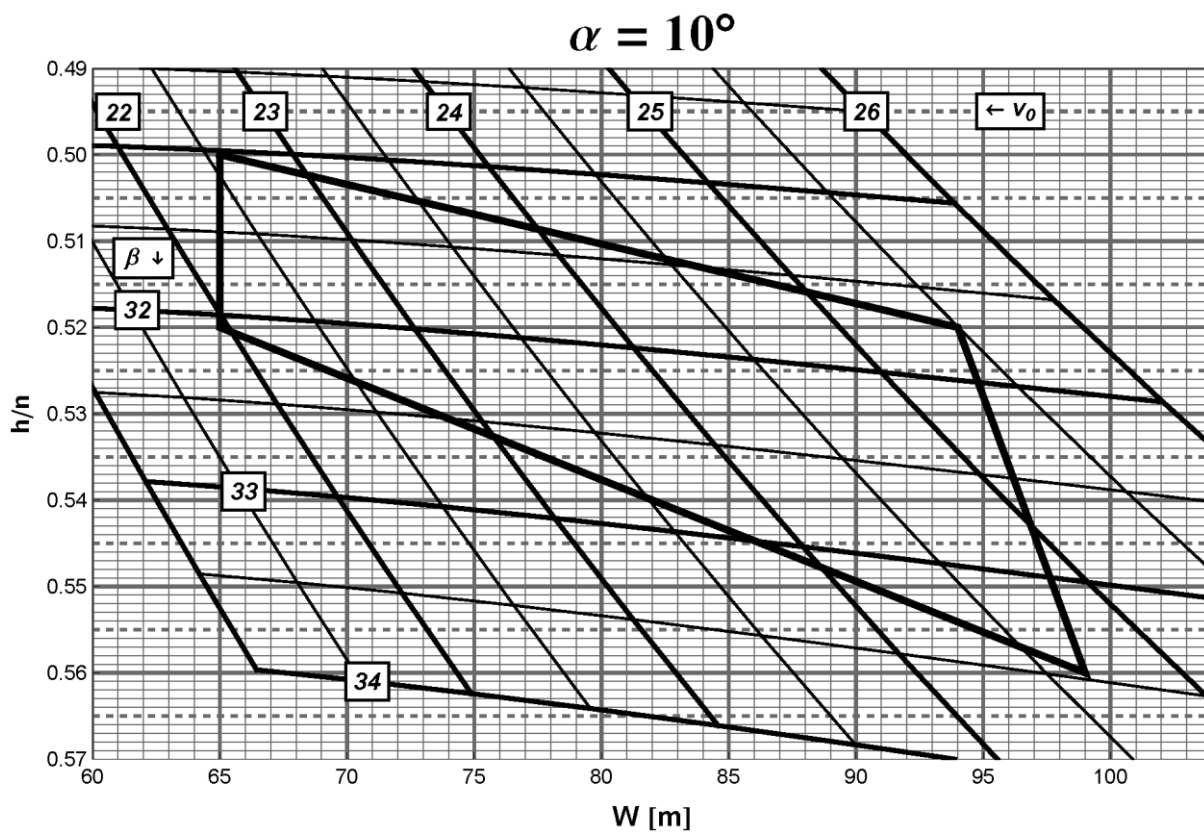


Fig. 7

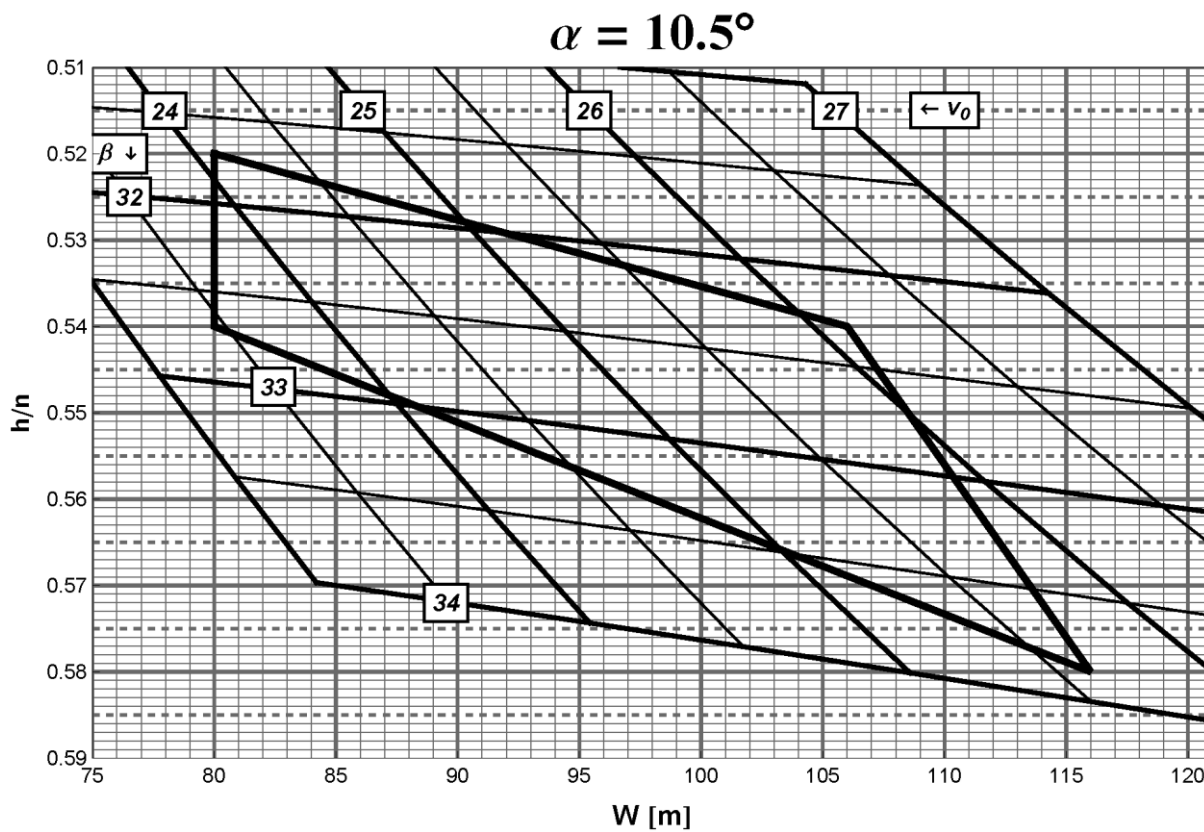


Fig. 8

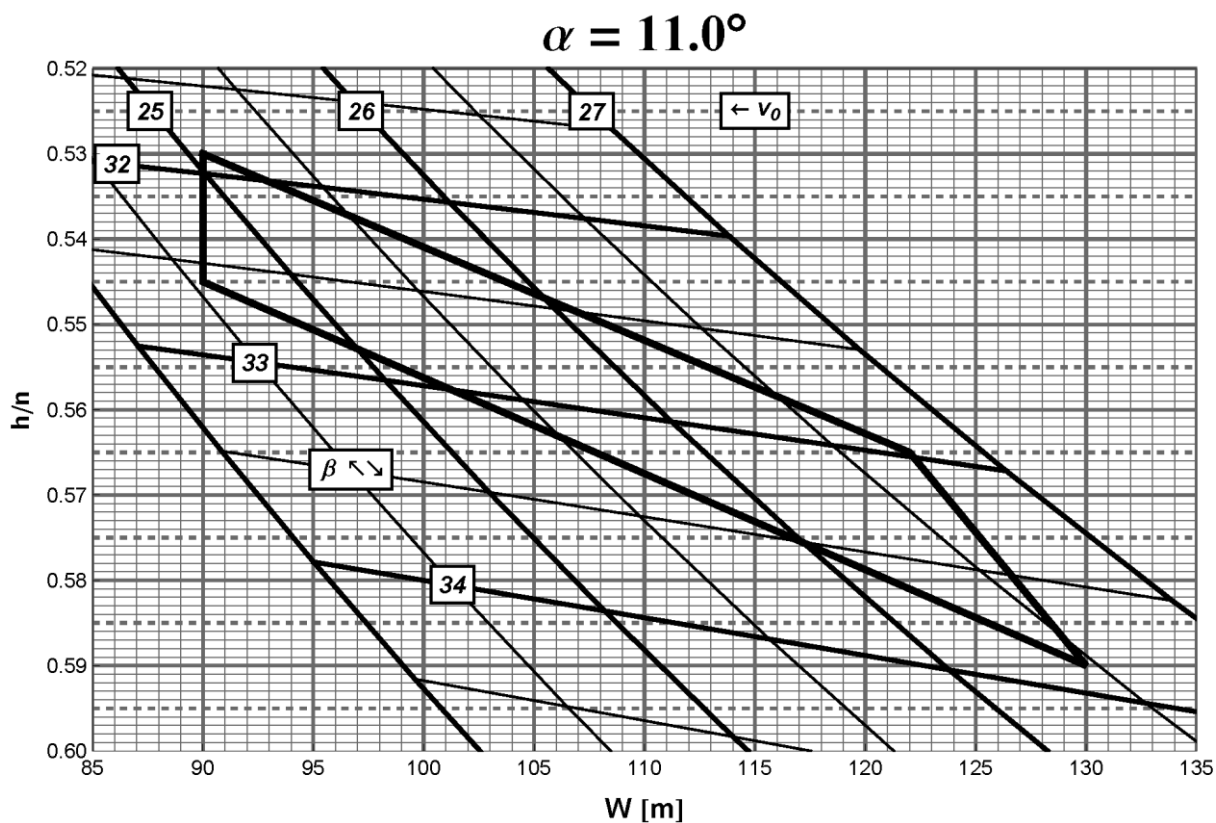


Fig. 9

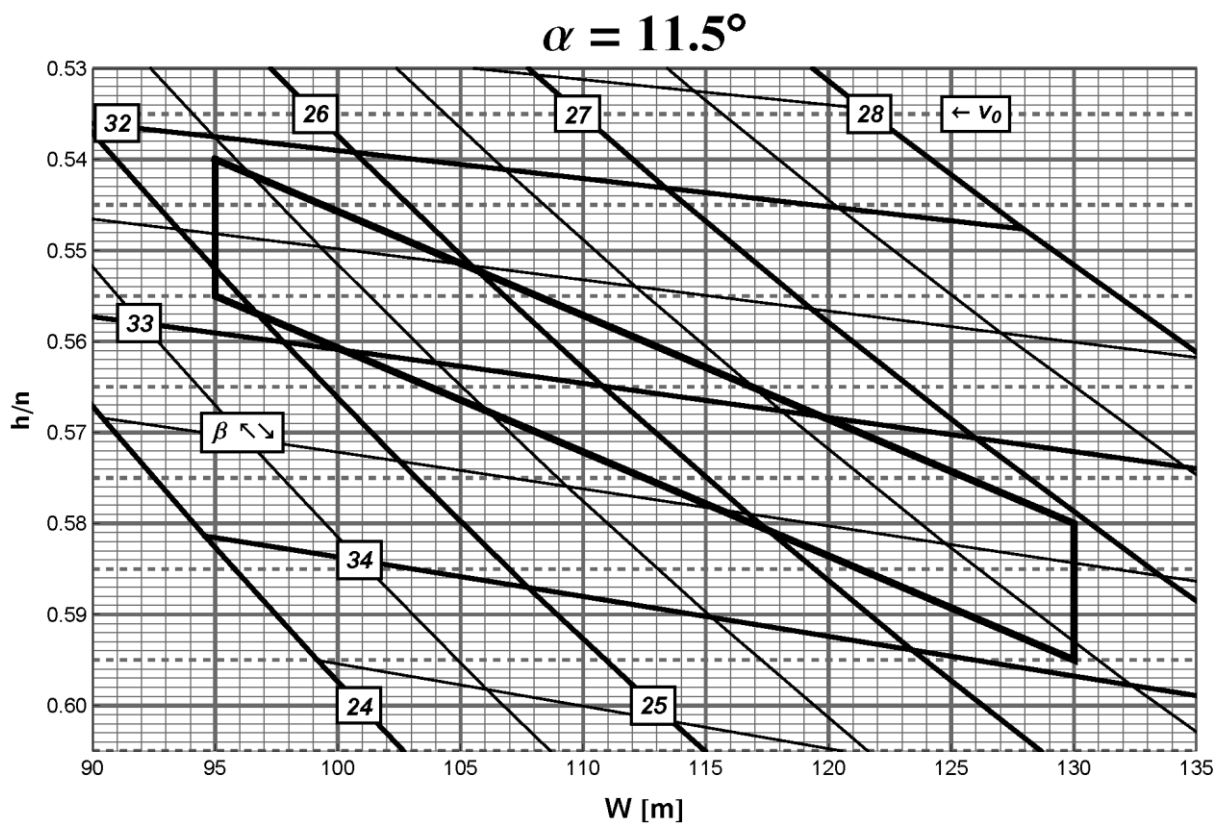


Fig. 10

From the five parameters (w , h/n , α , β and v_0), the lengths, angles, and point coordinates of the jumping hill elements will be calculated. For a first approximation the following formulas can be used. A better calculation is derived from "JUMP-2 1.4"

Lengths, angle and speeds:

$$HS = w + l_2$$

$$w = 0.885 \cdot HS + 1.5 \quad (\text{Approximation formula})$$

$$h = w \cdot \sin(\arctg(h/n)) / 1.005$$

$$n = w \cdot \cos(\arctg(h/n)) / 1.005$$

$$v_K = 0.68 \cdot v_0 + 12.44 \quad (\text{Landing speed at K; approximation formula})$$

$$r_L = v_K^2 \cdot w / 380, \text{ at least however } v_K^2 / 8 \text{ and rounding off on ten Meter-Increments.}$$

$$\beta_L = \beta - 1.4 / v_K \cdot 180 / \pi$$

$$v_{11} = v_K - 16 / v_K - 0.1 \cdot \rho \quad (\text{Max. speed. in L; friction angle } \rho \text{ in old degree})$$

$$\beta_P = \beta + \delta\beta \quad \begin{array}{l} \text{Recommendation for } \delta\beta: \alpha = 8.0^\circ \text{ and } 8.5^\circ \quad \delta\beta = 1.5^\circ \\ \phantom{\text{Recommendation for } \delta\beta:} \phantom{\alpha = 8.0^\circ \text{ and } 8.5^\circ} \quad \delta\beta = 2.0^\circ \\ \phantom{\text{Recommendation for } \delta\beta:} \phantom{\alpha = 8.0^\circ \text{ and } 8.5^\circ} \quad \delta\beta = 2.5^\circ \\ \phantom{\text{Recommendation for } \delta\beta:} \phantom{\alpha = 8.0^\circ \text{ and } 8.5^\circ} \quad \delta\beta = 3.0^\circ \\ \phantom{\text{Recommendation for } \delta\beta:} \phantom{\alpha = 8.0^\circ \text{ and } 8.5^\circ} \quad \delta\beta = 3.5^\circ \end{array}$$

$$\beta_0 = \beta_P / 6$$

$$r_{2Lmin} = v_{11}^2 / (18 - 10 \cdot \cos \beta_L)$$

$$r_{2min} = r_{2Lmin}$$

r_{2L} and r_2 can be freely choised within the boundaries

$$r_L \geq r_{2L} \geq r_{2Lmin} \quad \text{and} \quad r_{2L} \geq r_2 \geq r_{2Lmin};$$

Additionally it must be true that $z_U \geq -88$ m, and the acceleration shall nowhere exceed 18 m/s^2 through the transition curve to the out-run. For the preliminary studies, the earlier solution for an arc with radius

$$r_2 = v_K^2 / [20 \cdot \cos \beta_L + v_K^2 \cdot \beta_L / 7000 - 12.5] \quad (\text{Approximation formula})$$

can be used.

$$l_1 = \delta\beta \cdot r_L \cdot \pi / 180$$

$$l_2 = 1.4 \cdot r_L / v_K$$

Coordinates:

The coordinate system is defined in Fig. 1

Point	X	Z
P	$n - r_L^*(\sin\beta_P - \sin\beta)$	$-h - r_L^*(\cos\beta_P - \cos\beta)$
K	n	$-h$
L	$n + r_L^*(\sin\beta - \sin\beta_L)$	$-h - r_L^*(\cos\beta_L - \cos\beta)$

The design and construction of the landing hill knoll is supposed to be so, that the highest height of the flight path of the ski jumper, that jumps to K, is reached on the half jumping distance. The height of the take-off table shall be $s \leq w/40$. This claim is nearly fulfilled by the cubic parabola

$$z = -w/40 - x \cdot \text{tg}\beta_0 - (3 \cdot u - v) \cdot [x/P_x]^2 + (2 \cdot u - v) \cdot [x/P_x]^3 \quad (z \text{ values are negative})$$

$$\text{whereby } u = -P_z - w/40 - P_x \cdot \text{tg}\beta_0$$

$$\text{and } v = P_x \cdot (\text{tg}\beta_P - \text{tg}\beta_0).$$

4.3 Transition curve

The transition curve from point L until U (see Fig. 1) is a sloping placed (quadratic) Parabola (Fig. 12). She should receive the inclination β_L in the point L and should have a horizontal tangent in the point U. The curve radius r_{2L} and r_2 in the points L respectively U are freely selectable. Ideally the choice is $r_{2L} = r_L$.

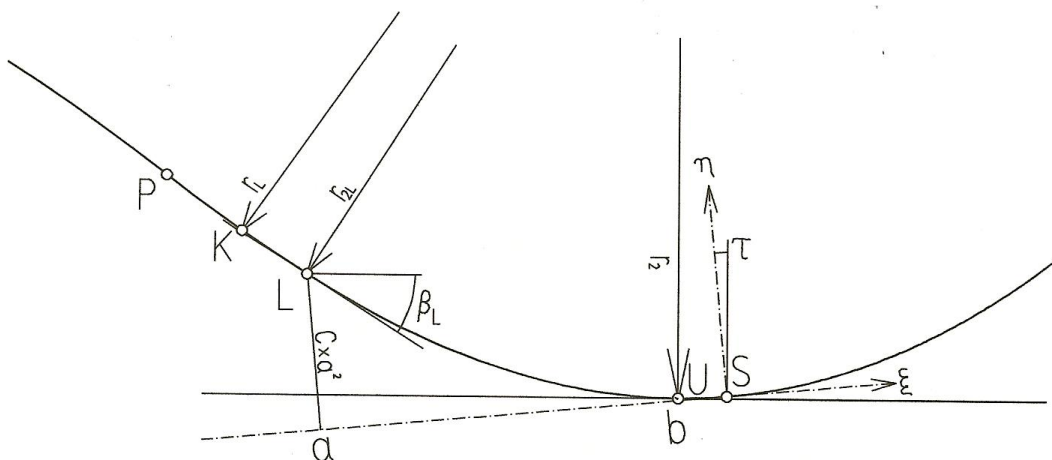


Fig. 11

The equation of the parabola in the twisted coordinate system is

$$\begin{aligned} \eta &= C \cdot \xi^2 \\ \text{with } \tau &= \arctan\{[\cos\beta_L - (r_2/r_{2L})^{1/3}]/\sin\beta_L\} \\ C &= 1/(2 \cdot r_2 \cdot (\cos\tau)^3) \\ a &= -\operatorname{tg}(\beta_L + \tau)/2/C \\ b &= -\operatorname{tg}(\tau)/2/C \end{aligned}$$

you will get

$$U = [x_L + C \cdot \sin\tau \cdot (a^2 - b^2) + \cos\tau \cdot (b - a); z_L - C \cdot \cos\tau \cdot (a^2 - b^2) + \sin\tau \cdot (b - a)]$$

The twisted coordinate system has its origin in S (parabolic vertex)

$$S = [x_L + C \cdot a^2 \cdot \sin\tau - a \cdot \cos\tau; z_L - C \cdot a^2 \cdot \cos\tau - a \cdot \sin\tau].$$

On large hills make sure that

$$z_U = z_L - C \cdot \cos\tau \cdot (a^2 - b^2) + \sin\tau \cdot (b - a) \leq -88 \text{ m}$$

is observed. (Art.411.2 ICR).

The replacement of the earlier related circle arch through the transition curve claims a larger height difference. On a large hill you must, if necessary, reduce r_{2L} and/or r_2 in order to get $z_U \leq -88$ m. One can also approximate the previous circle, if $r_{2L} = r_2$ is complied with.

The function $z(x)$ in the area of L until U is

$$z(x) = z_L - C \cdot \cos\tau \cdot (a^2 - \xi^2) - \sin\tau \cdot (a - \xi),$$

whereby

$$\xi = (\cos\tau - [(\cos\tau)^2 - 4 \cdot C \cdot (x - x_L - C \cdot a^2 \cdot \sin\tau + a \cdot \cos\tau) \cdot \sin\tau]^{0.5})/2/C/\sin\tau$$

is.

The radiuses r_{2L} and r_2 shall be set so that the normal pressure of the jumper in the whole transition curve is never greater than $1.8 \cdot g$. For this purpose there is no simple formula, as the number of free parameters is too large. It must be solved by the differential equation of the motion:

$$d(v^2)/ds = 2 \cdot g \cdot \sin(\varphi - \rho) - 2 \cdot (k + \rho/r) \cdot v^2.$$

The computer program 'JUMP2' makes this work very easy and quickly.

4.4 Out-run

The out-run length is

$$a = v_U + [v_U^2(1 - 0.006*v_U) - 300]/[9.6 - 20*\sin\delta] + 20, \text{ at least } 45 \text{ m}$$

whereby v_U is the speed in U and δ is the angle of the out-run area (δ is negative when out-run increases). Prefaced is „grippy“ snow. For summer operation with turf outrun, a is to be increased by 15 m.

v_U is obtained from the solution of the differential equation for the transition curve. A possible approximation is given by the equation

$$v_U = [8* v_K^2/(20*\cos\beta_L + v_K^2*\beta_L/7000 - 12.5)]^{0.5}.$$

A good approximation for a level outrun ($\delta = 0$) is

$$a = 18.9 + 1.113*w - 0.00482*w^2, \text{ at least } 45 \text{ m}.$$

In an uneven outrun profile, for example a hollow, it must be calculated in three sections

1. After U drive is unrestricted for one second, so in meters v_U .
2. Drive is under effect of gravity and braking by snow friction and air resistance, together of 4.8 m/s^2 , until the speed is decreased to 17.5 m/s .
3. 20 m for a turn or downangle.

4.5 Compilation of further recommended values and limits

$$t = 0.25v_0$$

$$S = 0.025w, \text{ at least } 0.70 \text{ m}.$$

The minimum prepared area of the in-run is at least

$$b_1 = 1.5 \text{ m} \quad \text{if } w \leq 30 \text{ m}$$

$$b_1 = 1.0 \text{ m} + w/60 \quad \text{if } 30 \text{ m} < w \leq 74 \text{ m}$$

$$b_1 = 1.5 \text{ m} + w/100 \quad \text{if } 75 \text{ m} < w \leq 99 \text{ m}$$

$$b_1 = 2.50 \text{ m} \quad \text{if } w > 100 \text{ m}$$

At most a maximum of 0.25 m more than these values.

Minimum widths of the prepared landing area and out-run (see Fig 1)

$$b_2 = 0.06w, \quad \text{however at least } 3.0 \text{ m}$$

$$b_k = 0.20w, \quad \text{however at least } 6.0 \text{ m}$$

$$b_U = 0.22w, \quad \text{however at least } 6.5 \text{ m}$$

5. Explanations by example

5.1 Basic specifications

Let it be a Normal Hill HS = 100 meters to design, that will be used by average and world class jumpers. Based on the existing ground countours $h/n = 0.55$ is assumed as favorable (smallest mass movement). The terrain is flat in the starting area, so that an artificial in-run tower has to be created.

5.2 Determination of table gradient α and take-off speed v_0

$$w = 0.885 \cdot HS + 1.5 = 90 \text{ m. (category normal Hill)}$$

It is necessary to consider which of the charts fig. 4 to fig. 11 lies the point $w = 90$ m and $h/n = 0.55$ within the marked, allowable range. That is in the charts fig. 8 and fig. 9 the case. We select the table inclination $\alpha = 10.5^\circ$. Through interpolation, one receives $v_0 = 24.25$ m/s and $\beta = 33.0$.

5.3 In-run Specifications

Because an artificial in-run is necessary, one selects the largest recommended inclination $\gamma = 35^\circ$.

With help of the approximation formulas we get the following in-run lengths:

$$e_1 = 92.3 - 1.517 \cdot 35 + 0.426 \cdot 100 = 81.8 \text{ m}$$

$$e_2 = 67.3 - 0.944 \cdot 35 + 0.331 \cdot 100 = 67.3 \text{ m.}$$

With help of the Excel programm „JUMP-2 2.0“ we enter the increased performance of 6% ($v_{alt}/v_{neu} = 1.06$) and get the following lengths:

$$e_1 = 84.2 \text{ m} \quad \text{the approximation has delivered a 2.4 m too short } e_1$$

$$e_2 = 70.7 \text{ m} \quad \text{the approximation has delivered a 3.4 m too short } e_2$$

$$r_1 = 0.14 \cdot (24.25 + 0.95)^2 = 88.90 \text{ m}$$

$$t = 0.25 \cdot (24.25 + 0.95) = 6.30 \text{ m}$$

The equations of chap. 4.1 deliver the elements of the transition curve

$$d = 61.05 \text{ m}$$

$$f = 9.27 \text{ m}$$

$$l = 62.32 \text{ m}$$

$$C = 0.00004076 \quad \text{and that}$$

$$\text{coordinates } E_1 = [-61.53 \quad 28.57]$$

$$E_2 = [-6.19 \quad 1.15]$$

The length of the transition curve l is 62.32 m. For the 35° steep straight part of the in-run from E_1 to B remains $e_2 - l - t = 69.7 - 62.3 - 6.3 = 1.1$ m.

We can get the coordinates of the highest and lowest starting place from the program „JUMP-2 2.0“:

$$A = [-74.29 \ 37.51]$$

$$B = [-63.29 \ 29.80].$$

5.4 The Landing Hill Profile

With $w = 90$ m, $h/n = 0.55$, $\beta = 33.0^\circ$ and $v_0 = 24.25$ m/s one receives in accordance with the formulas Chap. 4.2

$$h = 43.16 \text{ m}$$

$$n = 78.47 \text{ m}$$

$v_K = 28.93$ m/s as approximation. “JUMP-2 1.4” delivers exactly 29,00 m/s.

$$r_L = 200 \text{ m (rounded)}$$

$$\beta_L = 30.23^\circ$$

$$v_{11} = 28.35 \text{ m/s}$$

$$\delta\beta = 2.5^\circ$$

$$\beta_P = 33.00 + 2.50 = 35.50^\circ$$

$$r_{2L\min} = 89.0 \text{ m}$$

$$l_1 = 8.73 \text{ m} \quad l_2 = 9.67 \text{ m}$$

$$l = 18.40 \text{ m}$$

$$\beta_0 = 5.90^\circ$$

$$P [71.26 \ -38.25]$$

$$K [78.47 \ -43.16]$$

$$L [86.71 \ -48.23]$$

5.5 The transition curve

The boundary radii r_L and $r_{2L\min}$ are 200 m respectively 89.0 m. The large gap is supposed to be exploited in addition to adapt the transition curve optimally to the available ground terrain (but the acceleration must be kept under 18 m/s^2 at the same time. In addition a quick visualization of the attempts is desired. The Computer program „JUMP-2 1.4“ offers additional assistance to get quick visualization of tests.

With for example $r_{2L} = 150$ m and $r_2 = 90$ m are the coordinates of U

$$U [141.08 \ -64.26];$$

the largest acceleration of $18,005 \text{ m/s}^2$ is reached approximately at 11 m before U.

5.6 The Out-run

The differential equation delivers the speed in U of 26.77 m/s.
 Therewith the out-run length is in horizontal grounds $a = 79$ m.

5.7 Prepared Widths

The prepared widths are at least

$b_1 = 2.4$ m, but not larger than 2.65 m.

$b_2 = 5.4$ m

$b_K = 18$ m

$b_U = 20$ m

6. Further construction specifications of a ski jumping hill

6.1 In-run

The start places in the area of e_s are in same distances to arrange whereby the height difference between two start places may not be larger than 0.40 m. They are to be consecutively numbered, beginning with the No. 1 for the lowest place.

The lateral limitation of the snow levels results through profile rails, that allows adequate preparation of the snow profile on the in-run. In addition, a solid guardrail / deflection boards at least 50 cm high must be mounted from the lowest start place until at least 1 m before the take-off edge. Width of the inrun between the guardrails should at most be $b_1 + 0.25$. Within these guardrails, there shall not be any protruding obstacles. The beginning of these guardrails must emerge out horizontally from the in-run and must be rounded off on the edges.

For the artificial in-run towers it is recommended to put insulation under the snow, to prevent thawing from below.

6.2 The Landing Hill Profile

The landing hill must be prepared with snow to the full width that is in accordance with the hills homologation. Protruding obstacles are not allowed in the prepared area and must be removed, and of course all equipment used to prepare the hill shall be removed prior to the use of the jumping hill for any ski jumping.

Guardrails must project at least 70 cm over the snow profile. These guardrails shall be inplaced from $0.1w$ to the point U. The proper snow profile and the marks of the different distances from the take-off shall be marked on the side boards. The beginning of the guardrails must emerge horizontally out of the hill and must be rounded off at the edges in its entire legth.

Furthermore guardrails with a height of 1 m over the snow profile must be mounted from U around the entire out-run area over. The guardrails must be constructed so, that they can resist to the impact of a fallen skier and/or the impact of a run away ski and not allowing them to project outward.

6.3 The judges' tower

The placement of the judges' tower is restricted through the following limits

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

$$q = 0.25w \text{ until } 0.50w$$

The level of the judge's cabins are to be determined so that the line of sight of the judge to the ski jumper in its flight from the take-off edge until at least the fall line is guaranteed. At the same time guardrails, embankment edges and items such as chair lifts between the judges' tower and the landing hill shall be considered.

For two ski jumps with a common out-run, the creation of one judges tower will be sufficient if the height difference between both K points is not more than 3 meters. The tower shall be on the side of the small hill. Height and location of the cabins must be determined by the larger jump hill, but with the minimum distance q shall not fall below that based on the small hill.

The cabins for the judges must be separated by firm partitions from one another and have a minimum size of 1.0 m wide and 1.2 m deep.

The window sill height should be 1.00 m. Cabins must be constructed so, that the judge can not see the marks of his/her colleagues. There should also be a cabin for the Chief of Competition and the TD, where from they can work without interruption during the competition.

It is recommended to construct the judges cabins in a „staircase“ pattern that follows the jumpers flight path. However, if the judges' cabins are used for both a Large and a Normal jumping hill, then the staircase pattern to follow the flight path must be adapted.

The location of the jury room where the person responsible for releasing the ski jumper is, has to be chosen so, that it is possible to see the jumper from the upper most starting place to the take-off and throughout the flight, landing and outrun phase. If for some reasons it is not possible to see the entire jump from this place, then for larger events cameras should cover the areas so, they can be monitored via live video.

6.4 Trainers Platform

On normal hills and large hills, there shall be two trainers platforms that hold at least 20 trainers; one platform to view the take-off area and another to view the landing area.

In OWG-, WCS- and WCJ-contests, the platforms must be able to hold at least 40 trainers each.

The minimum distance of the front edge of the trainer platform to the axis of the jumping hill is 12m.

6.5 Chairlift

At a jumping hill, on which OWG and WCS competitions take place, there must be a chairlift or other sufficient mechanical ascent mechanism for the ski jumpers

6.6 Warming House/Area

In OWG-, WCS-, SFWCS-, JWCS- and WCJ contests there must be a warming room or tent in the start area for at least 20 athletes.

7. Additional notes / references

Designing a profile for a jumping hill is more complex in reality. In the above-mentioned example, h/n and β were just estimated in order to make the first assumptions in the calculations. The profile derived from that can then be overlayed on the ground contours. Then a first correction will impose itself as needed, for example the point U lies already under the out-run level given or perhaps because the estimated h/n is too small. In order to solve this complex problem optimally and quickly, the computer program "JUMP-2 14" has been created and supplemented with "JUMP-2 2.0" excel computer program.

It can be ordered from the

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