

Forgások biomechanikája

Megkülönböztetjük:

- Sportoló mozgása
- Sportszer mozgása
- Sportoló és sportszer együttes mozgása

Rotáció

Transzláció és rotáció

Mozgás talajon

Mozgás levegőben

Fizikai mennyiségek

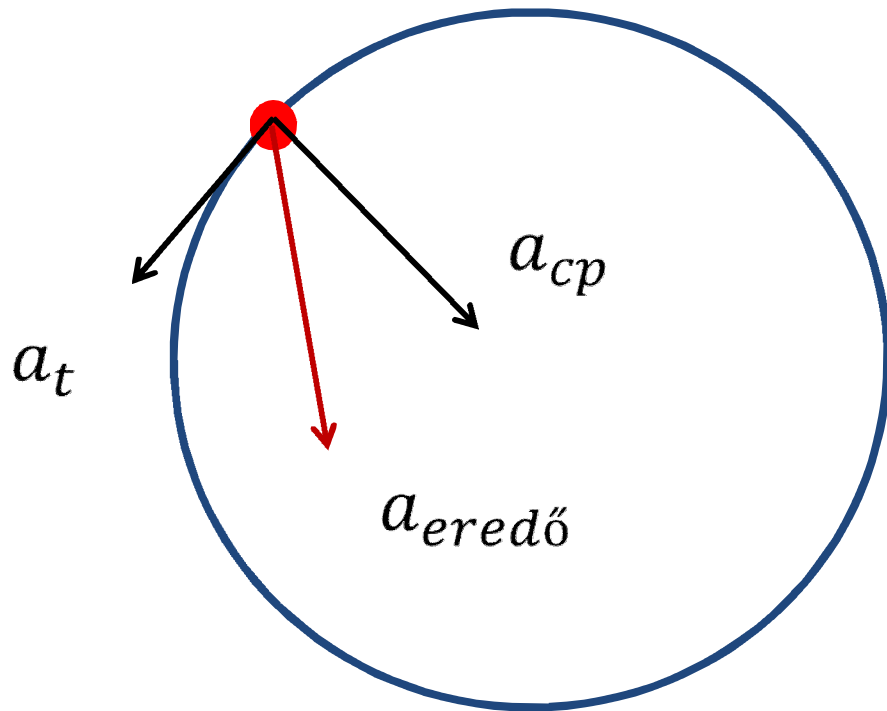
Transzláció

- s
- v
- a
- m
- $l = m * v$
- $F = m * a$
- $E = \frac{1}{2} m * v^2$
- Impulzusmegmaradás

Rotáció

- α
- ω
- β
- $\theta = \sum m_i * r_i^2$
- $N = \theta * \omega$
- $M = \theta * \beta$
- $E = \frac{1}{2} \theta * \omega^2$
- Perdületmegmaradás

Gyorsulások



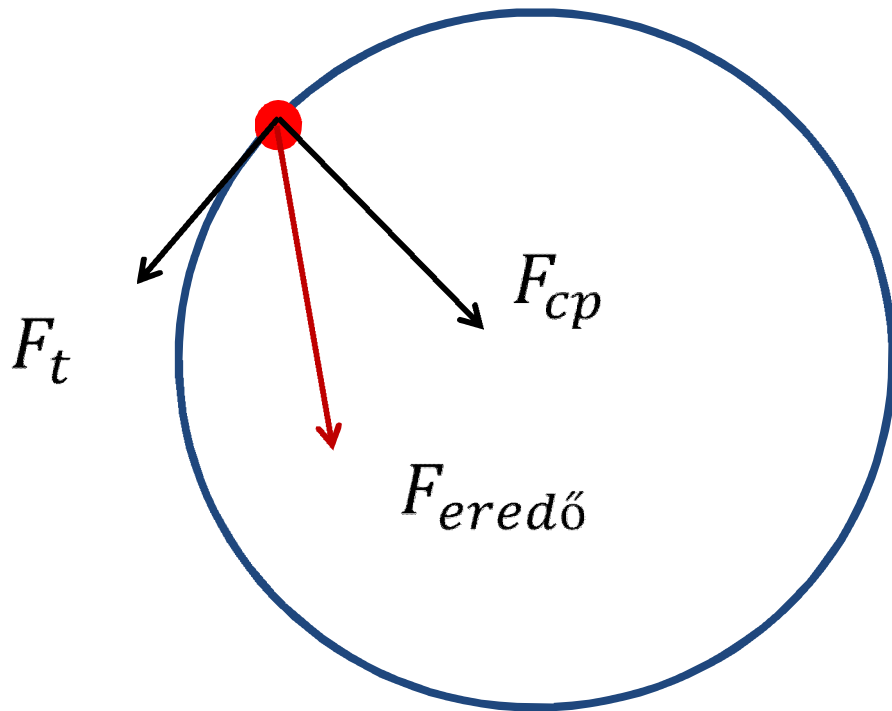
$$a_{cp} = \frac{v^2}{r} = r * \omega^2$$

$$a_t = r * \beta$$

$$a_{eredő} = \sqrt{a_t^2 + a_c^2}$$

$$F_{eredő} = m * a_{eredő}$$

Dinamikai jellemzők



$$F_{cp} = m * \frac{v^2}{r}$$

vagy

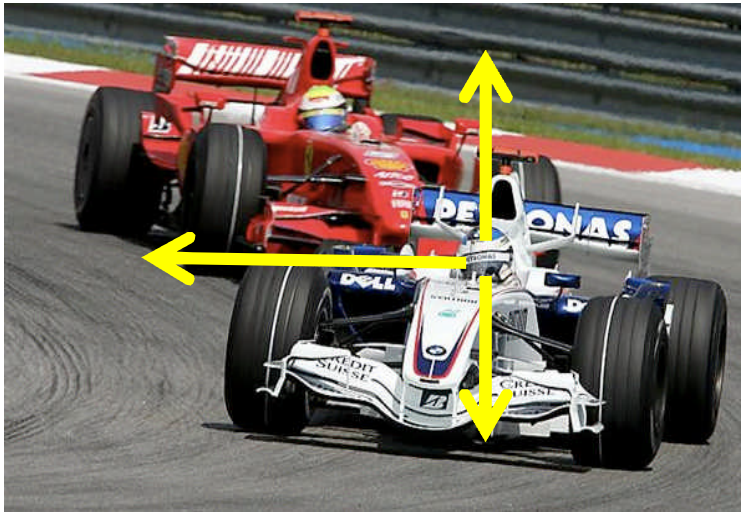
$$F_{cp} = m * r * \omega^2$$

$$F_t = m * a_t$$

$$F_{eredő} = \sqrt{F_t^2 + F_{cp}^2}$$

Ha $v_{tang} = \text{állandó}$ $\Sigma F = F_{cp}$

Centripetális erő – Forma 1



$$m_{fej+sisak} = 8kg$$

$$v_{tang.} = 180 \frac{km}{h} = 50 \frac{m}{s}$$

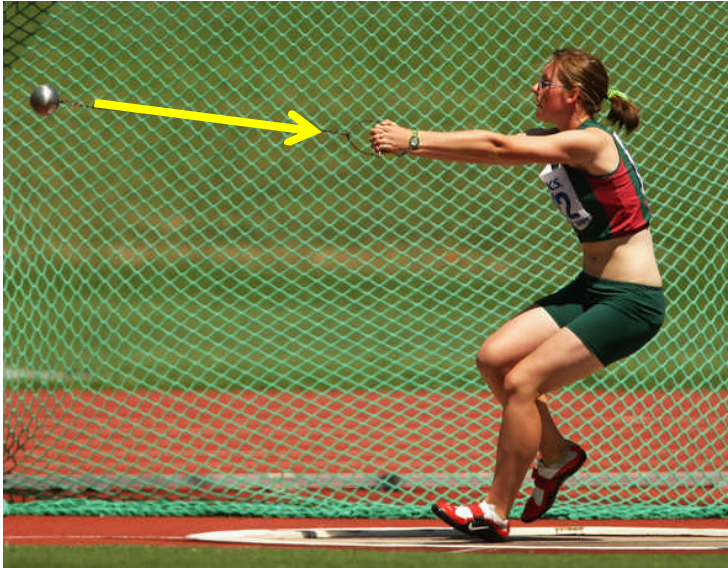
$$d=100m \Rightarrow r=50m$$

$$F_{cp} = m * \frac{v^2}{r}$$

$$F_{cp} = 8 * \frac{50^2}{50}$$

$$F_{cp} = 400N = 5 * mg$$

Kalapácsvetés



$$m_{\text{kalapács}} = 7.5\text{kg}$$

$$r = 1.8\text{m}, T = 0.5\text{s}$$

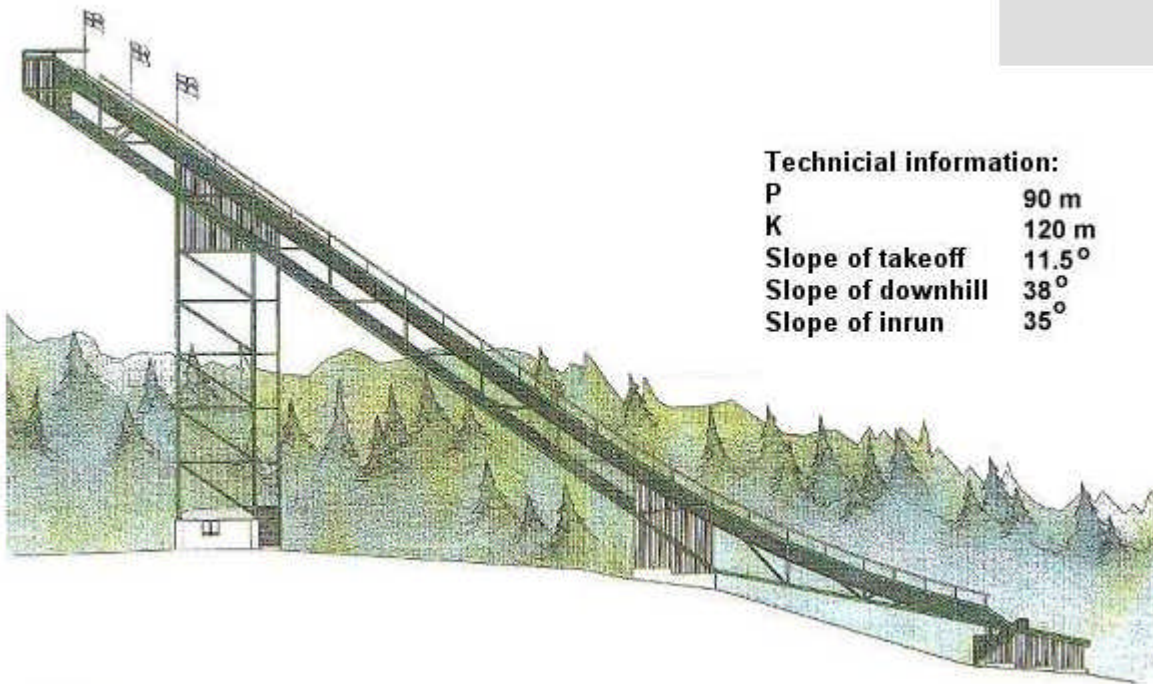
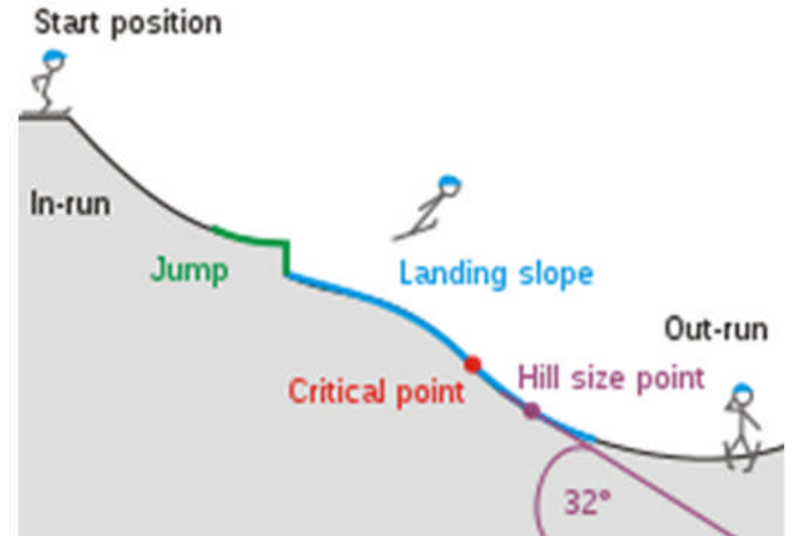
$$v_{\text{tang.}} = \frac{2r\pi}{T} = \frac{2 * 1.8 * 3.14}{0.5} \\ = 22.6 \frac{\text{m}}{\text{s}}$$

$$F_c = m * \frac{v^2}{r}$$

$$F_c = 7.5 * \frac{22.6^2}{1.8} = 2128\text{N}$$



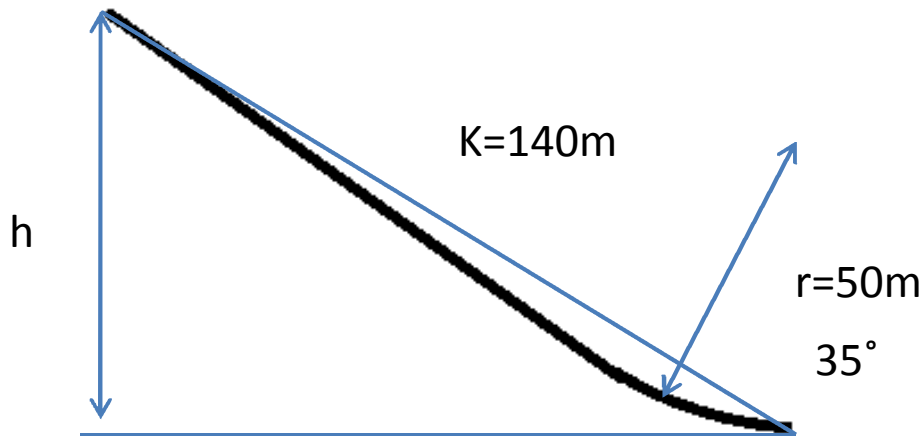
Síugrás



Technical information:

P	90 m
K	120 m
Slope of takeoff	11.5°
Slope of downhill	38°
Slope of inrun	35°

Síugróra ható erők elrugaszkodásnál



$$h = K * \sin(35^\circ)$$

$$h=80.3\text{m}$$

$$mgh = \frac{1}{2}mv^2$$

$$v = \sqrt{2gh}$$

$$v=40\text{m/s}$$

Közegellenállás, súrlódás miatt:

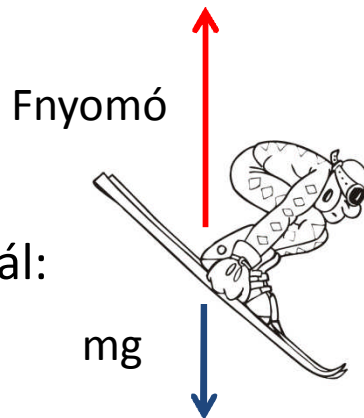
$$v=28\text{-}30\text{m/s}$$

$$\text{Fnyomó} - mg = m \frac{v^2}{r}$$

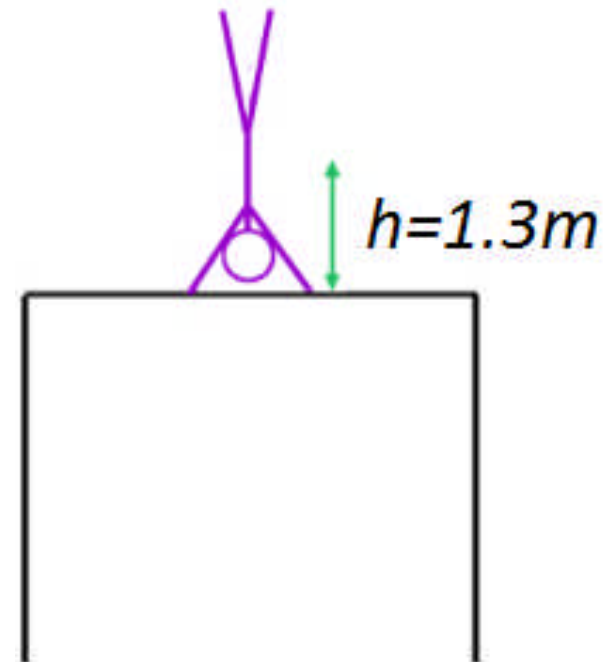
$$\text{Fnyomó} = mg + m \frac{v^2}{r} = mg + 1.8mg$$

$$\text{Fnyomó} = 2.8mg$$

Elrugaszkodásnál:



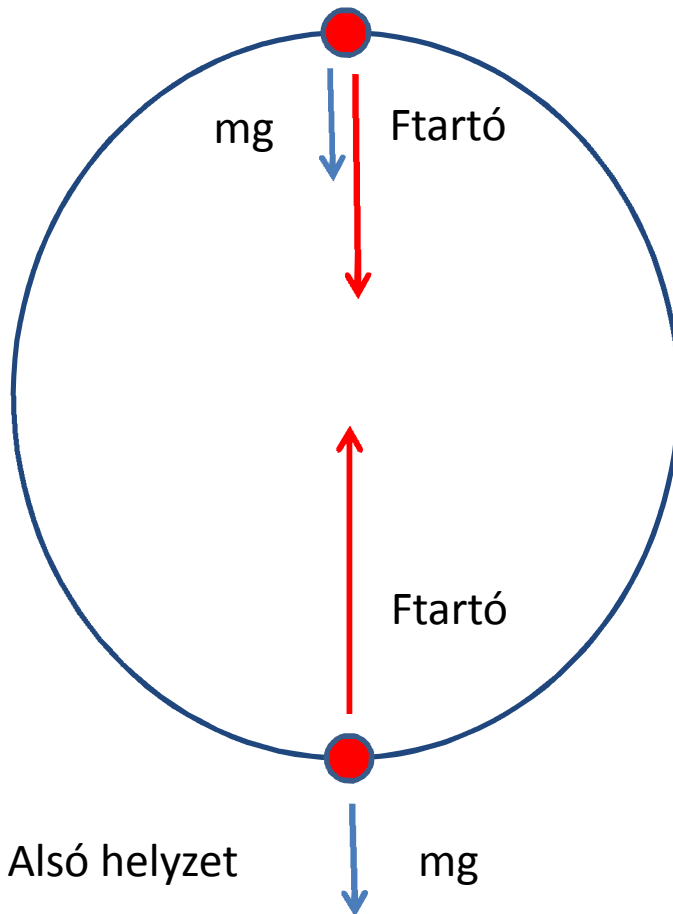
Nyújtó



Erők a felső és alsó helyzetekben

(Feltételezés: tornász pontszerű)

Felső helyzet



Alsó helyzet

Felső helyzet:

$$F_t + mg = F_{cp}$$

$$\text{Ha } F_t = 0 \quad mg = m \frac{v^2}{r}$$

$$v = \sqrt{gr} = 3.6 \text{ m/s} \quad r = 1.3 \text{ m}$$

Alsó helyzet:

$$\sum \text{Energia fent} = \sum \text{Energia lent}$$

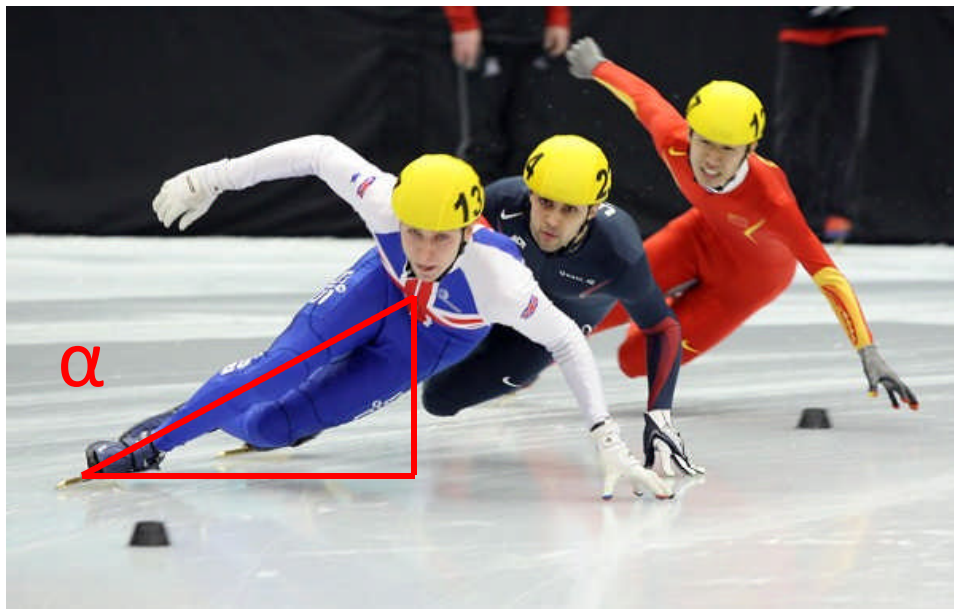
$$mgh + \frac{1}{2}mv_{fent}^2 = \frac{1}{2}mv_{lent}^2 \quad h = 2r = 2.6 \text{ m}$$

$$v = 8.06 \text{ m/s}$$

$$F_t - mg = F_{cp} \quad F_t = F_{cp} + mg$$

$$F_{tartó} = mg + m \frac{v^2}{r} = mg + 5mg$$

$$F_{tartó} = 6mg$$



Gyorskorcsolya

$$F_y = mg$$

$$F_y / F_x = \tan \alpha$$

$$F_x = m * a_{cp} = m * \frac{v^2}{r}$$

$$v = 48 \text{ km/h} = 13.3 \text{ m/s}$$

$$r = 10 \text{ m} \quad m = 60 \text{ kg}$$

$$a_{cp} = \frac{13.3^2}{10} = 17.7 \frac{\text{m}}{\text{s}^2}$$

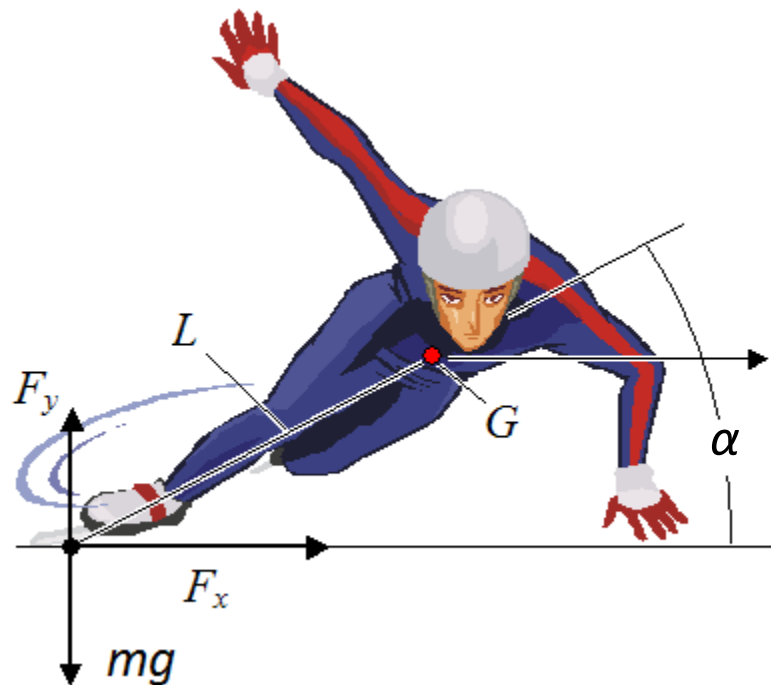
$$F_{cp} = F_x = 60 * 17.7 \frac{\text{m}}{\text{s}^2} = 1062 \text{ N}$$

$$F_y = 60 * 10 \frac{\text{m}}{\text{s}^2} = 600 \text{ N}$$

$$F_{talajr} = \sqrt{F_x^2 + F_y^2} = 1219 \text{ N} \approx 2 * mg$$

$$\frac{F_y}{F_x} = 0.56 \quad \alpha = 29.5^\circ$$

Támasztás egy hajlított lábbal!



Perdületmegmaradás tétele

$$\Sigma M = \frac{dN}{dt} = \theta * \beta$$

Ha a forgatónyomatékok összege nulla, a test perdülete nem változik meg, a perdület állandó.

$$\Sigma M = \frac{dN}{dt} = 0 \quad N = \text{állandó}$$

$$N = \theta * \omega = \text{állandó}$$

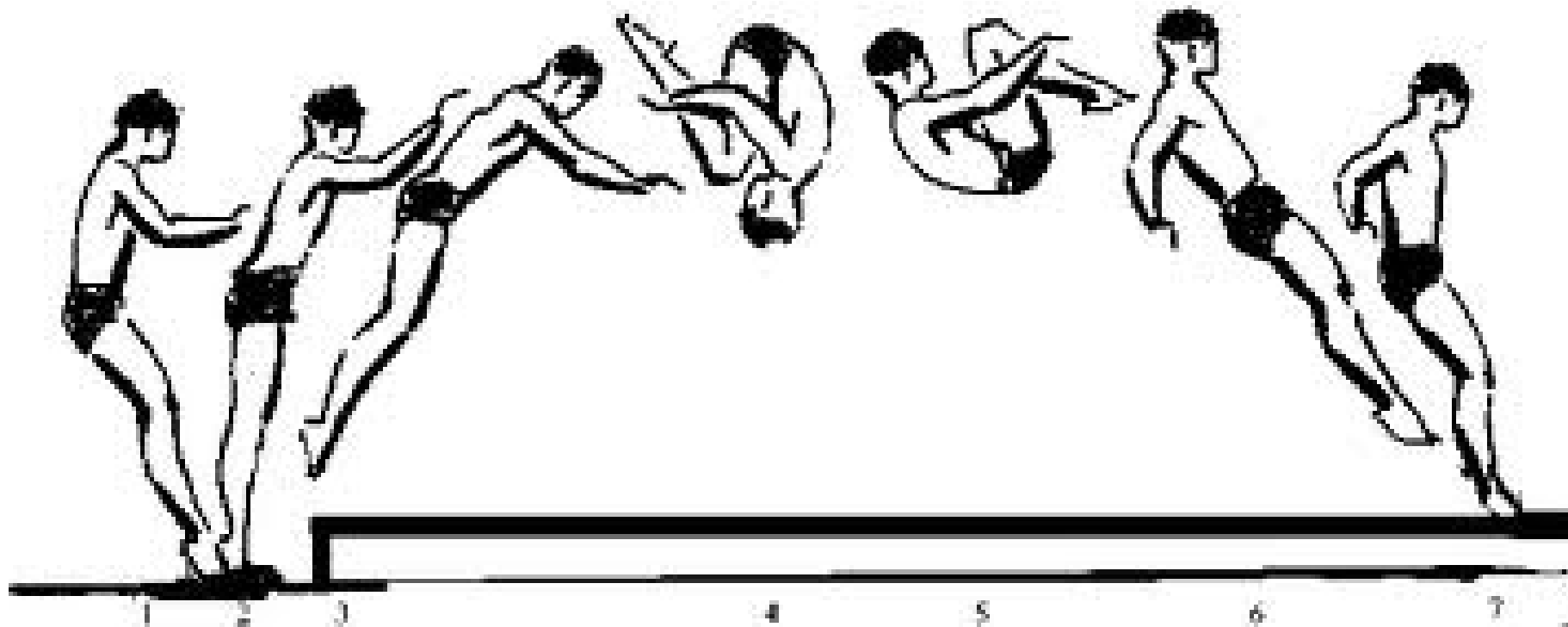
$$N = \theta_1 * \omega_1 = \theta_2 * \omega_2$$

$$\theta = \Sigma m_i r_i^2$$

$$\theta_1 > \theta_2 \quad \longrightarrow \quad \omega_1 < \omega_2$$

Példa: Műkorcsolya, piruett

Szaltó – forgás a levegőben



Perdületmegmaradás tételének alkalmazása

$$\Sigma M = \frac{dN}{dt} = \theta * \beta$$

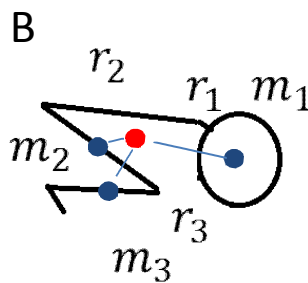
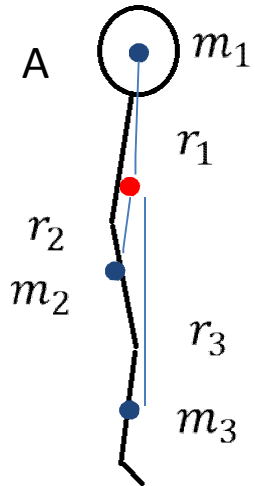
Elrugaszkodás után N állandó

(Pálya alakja ferde hajítás miatt parabola)

Tehetlenségi nyomaték megváltoztatásával a forgási sebesség befolyásolható

$$N = \theta_1 * \omega_1 = \theta_2 * \omega_2$$

RD

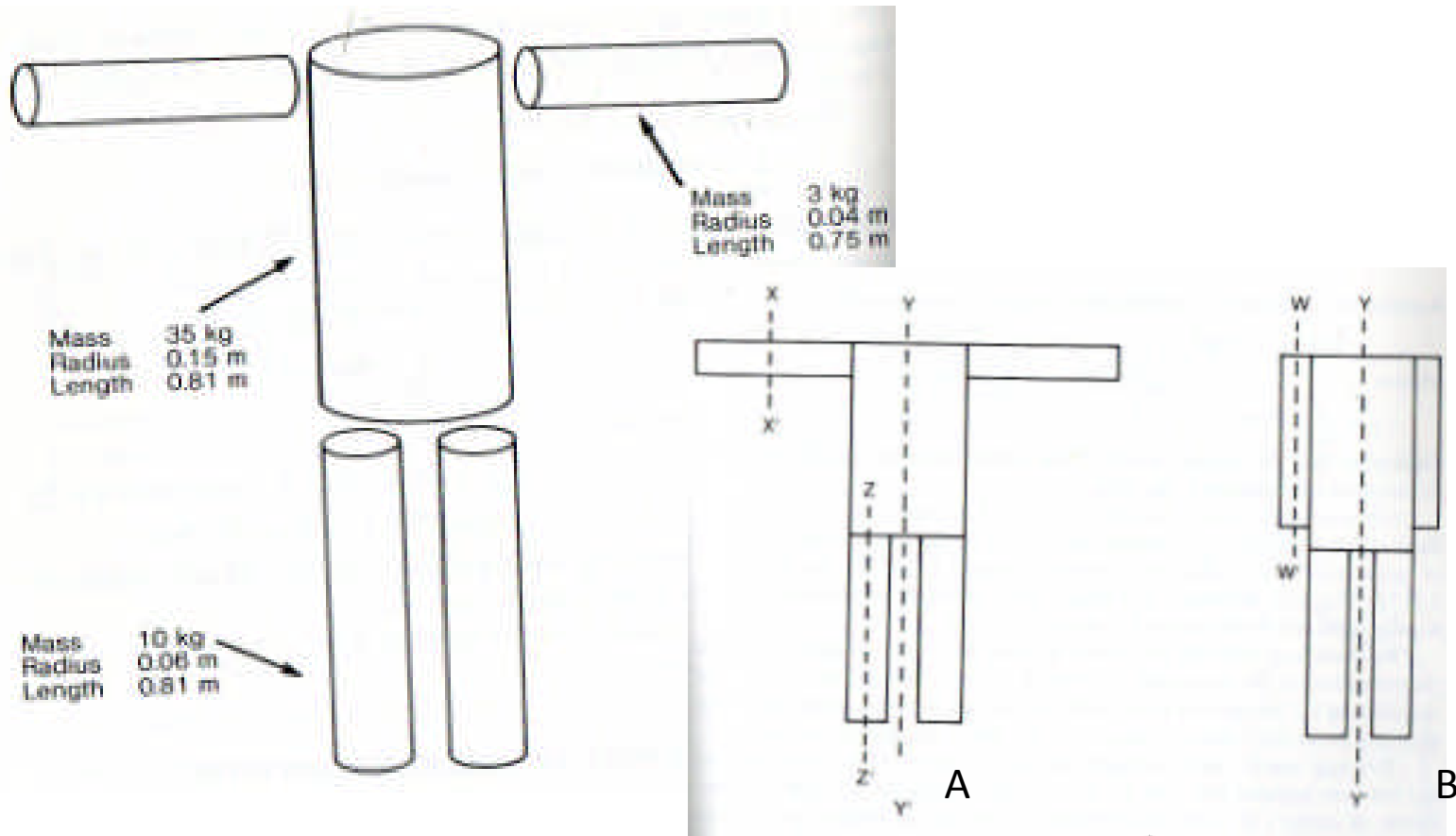


$$A: r_1, r_2, r_3 > B: r_1, r_2, r_3 \quad \theta = \Sigma m_i r_i^2$$

$$A: m_1 r_1^2 + m_2 r_2^2 + m_3 r_3^2 > B: m_1 r_1^2 + m_2 r_2^2 + m_3 r_3^2$$

$$\theta_A > \theta_B \quad \longrightarrow \quad \omega_A < \omega_B$$

Alkalmazás műkorcsolya forgás esetén

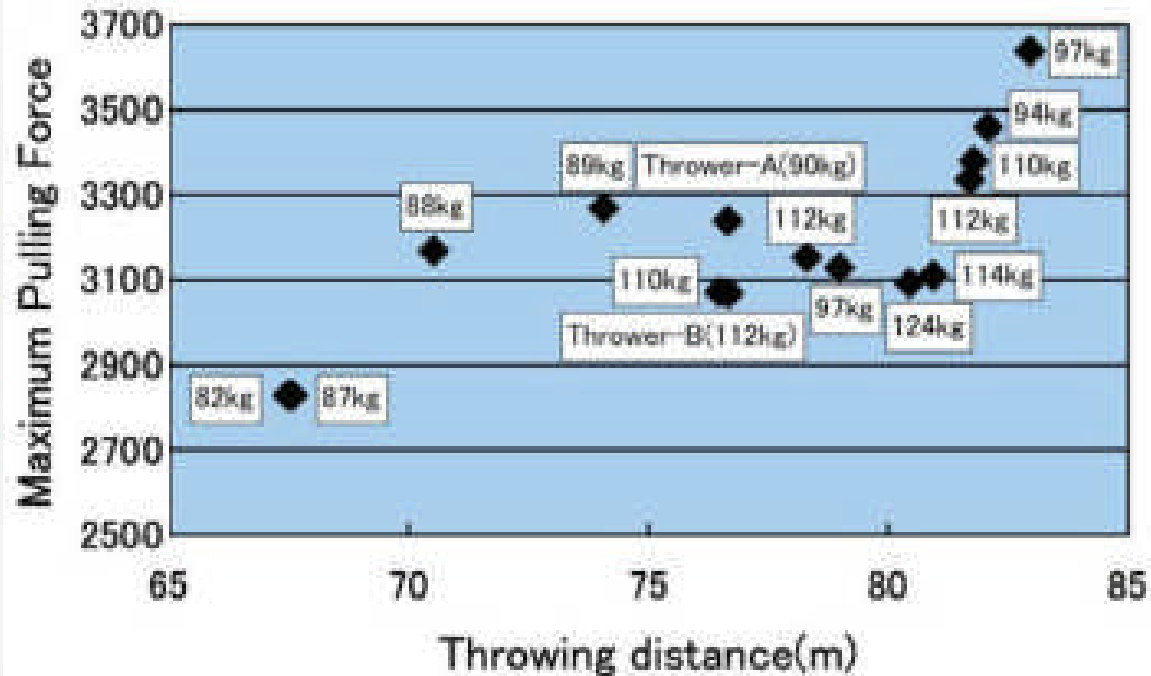
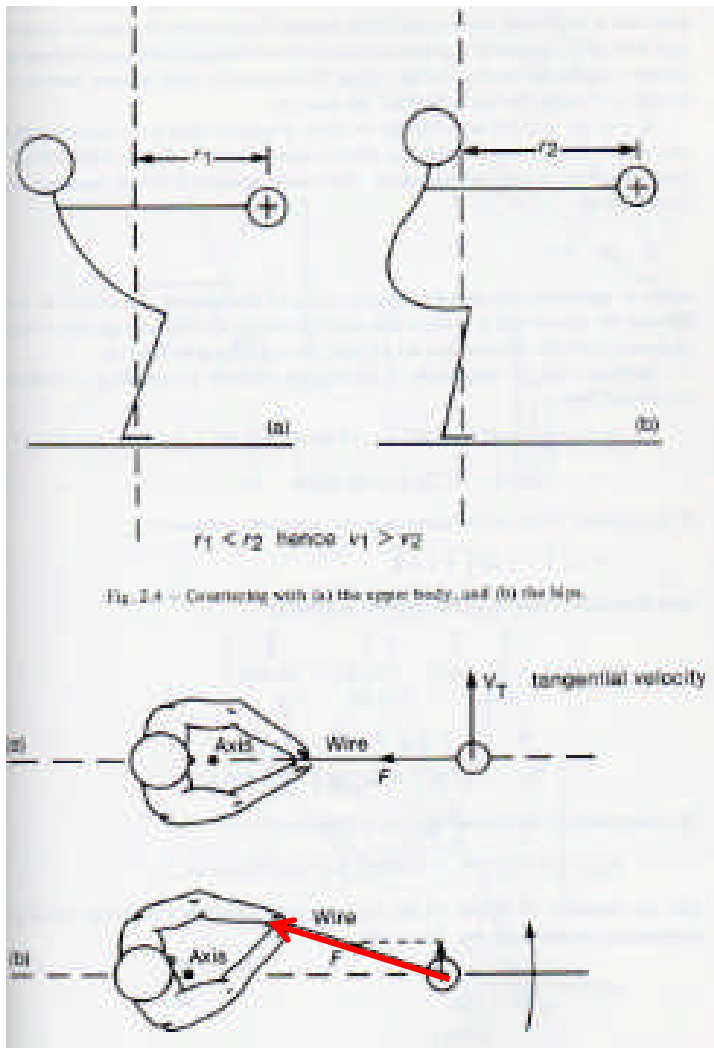


$$N = \Theta_A * \omega_A = \Theta_B * \omega_B \quad \theta_A = 2.52 \text{ kgm}^2 \quad \theta_B = 0.81 \text{ kgm}^2$$

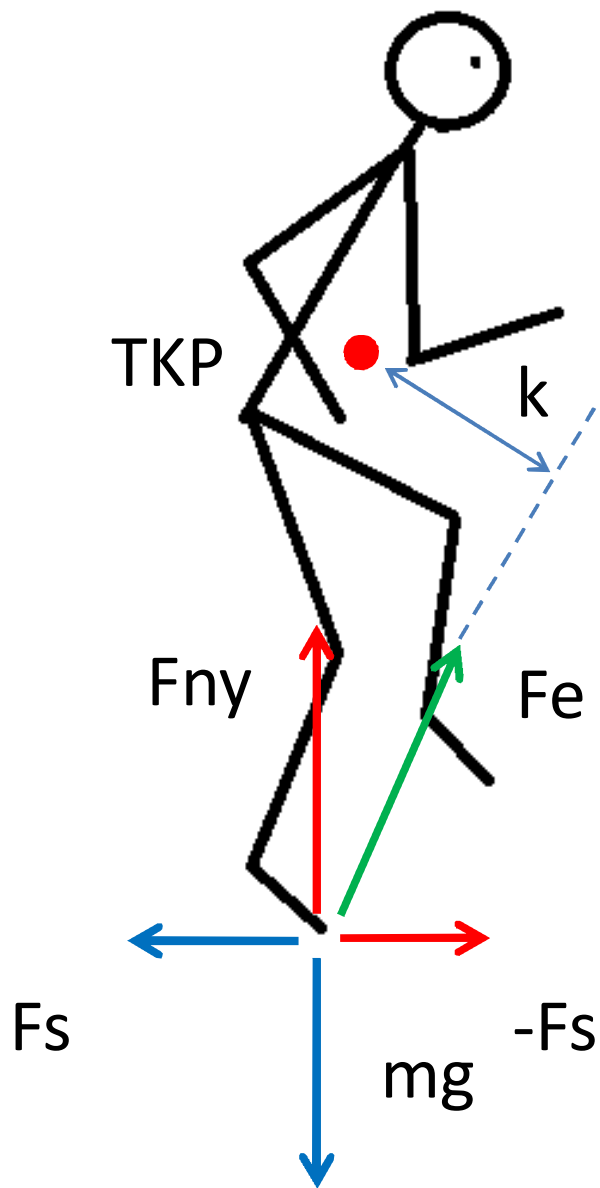
Ha $\omega_A = 2.5 \text{ s}^{-1}$ $N = 2.52 * 2.5 = 6.32 \text{ kgm}^2 \text{ s}^{-1} = \text{állandó}$

$$\omega_B = \frac{N}{\theta_B} = 7.78 \text{ s}^{-1}$$

Kalapácsvetés II

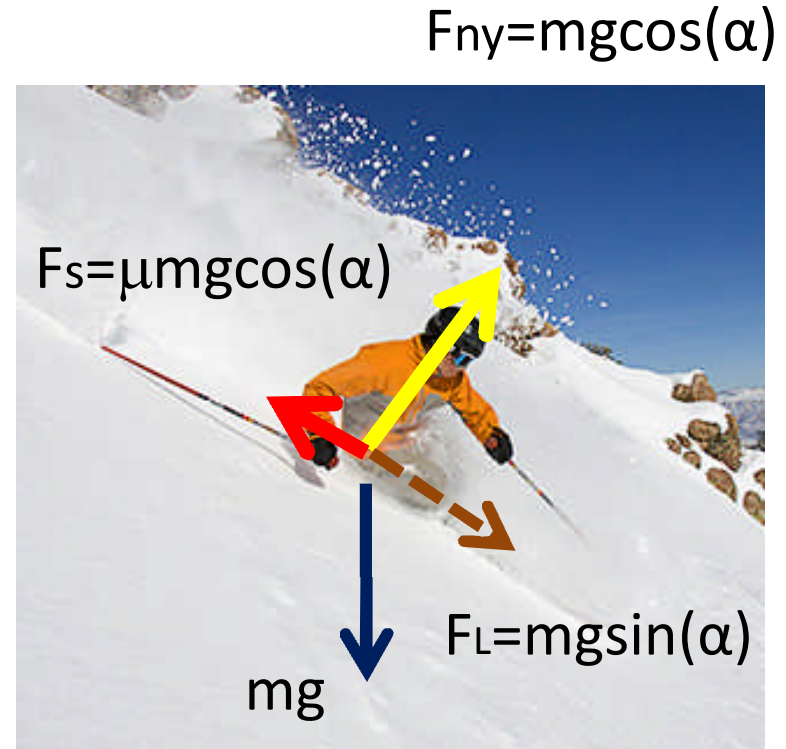
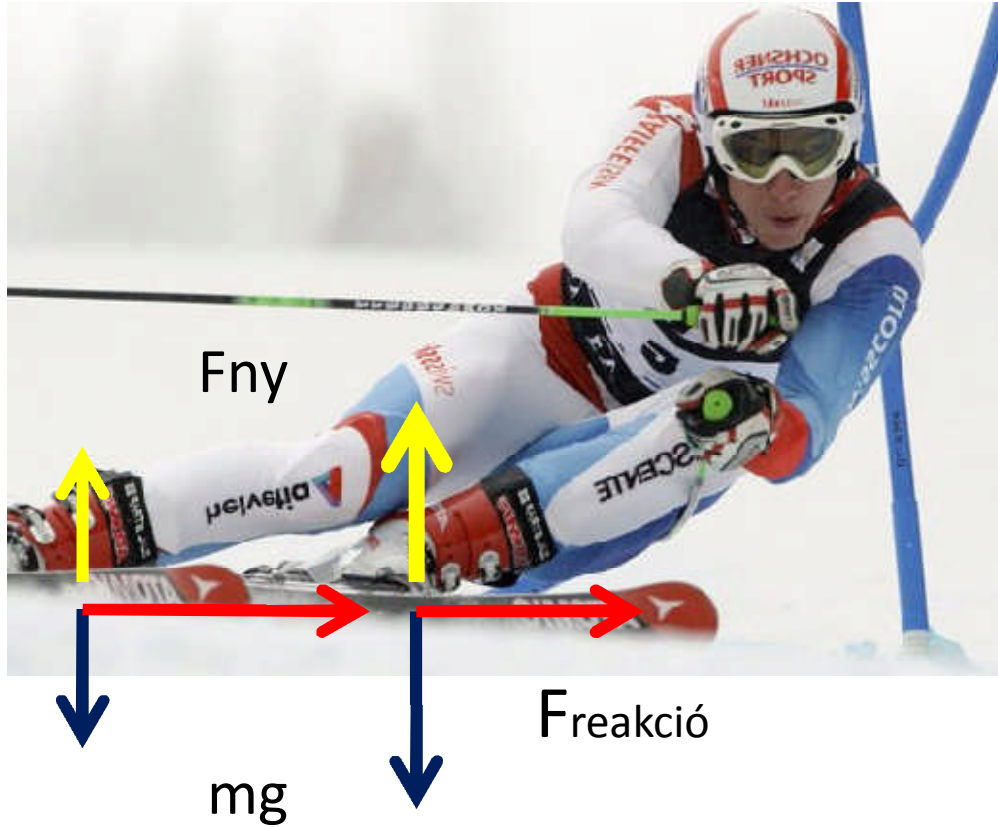


Van tangenciális erőkomponens \Rightarrow nő a szögsebesség

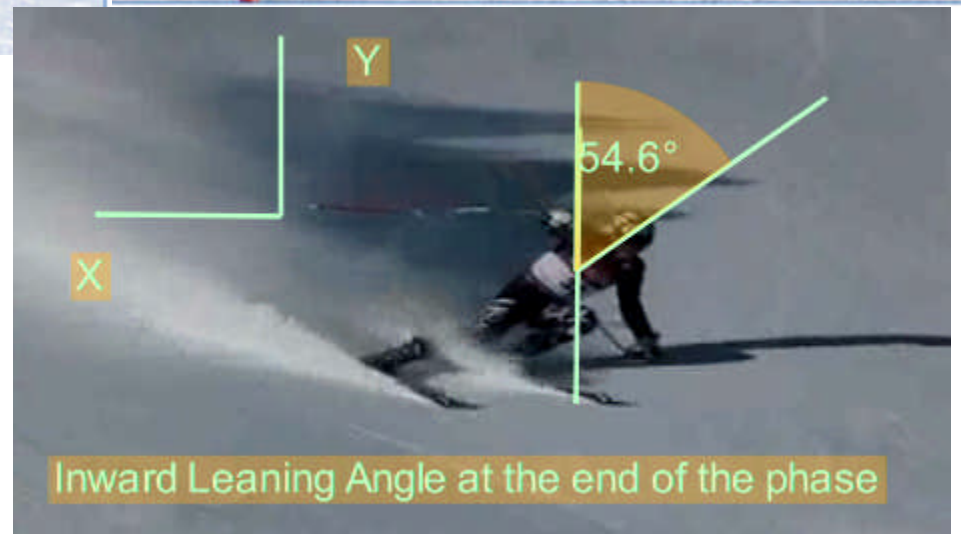
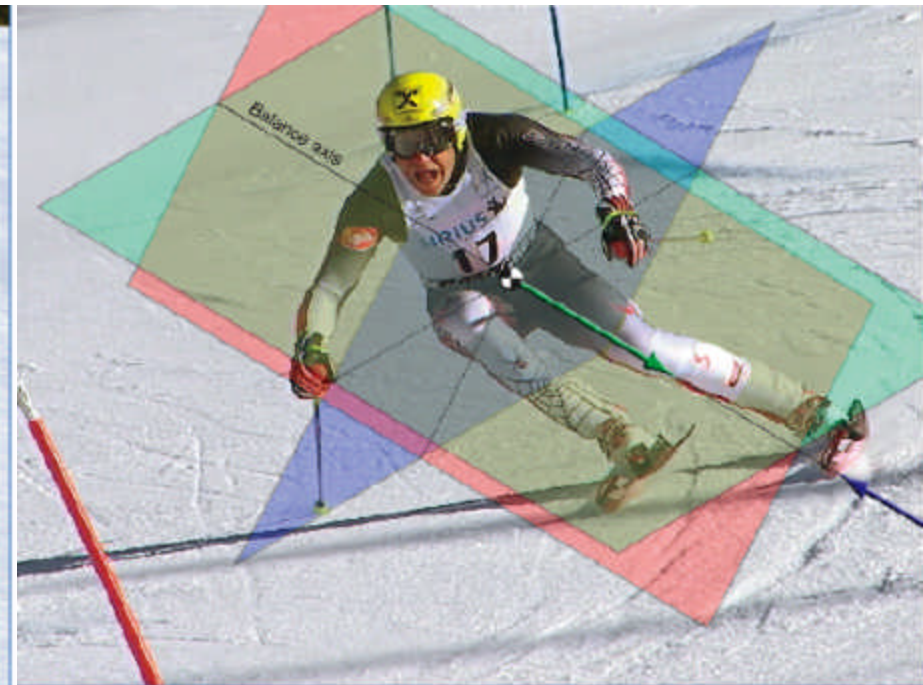
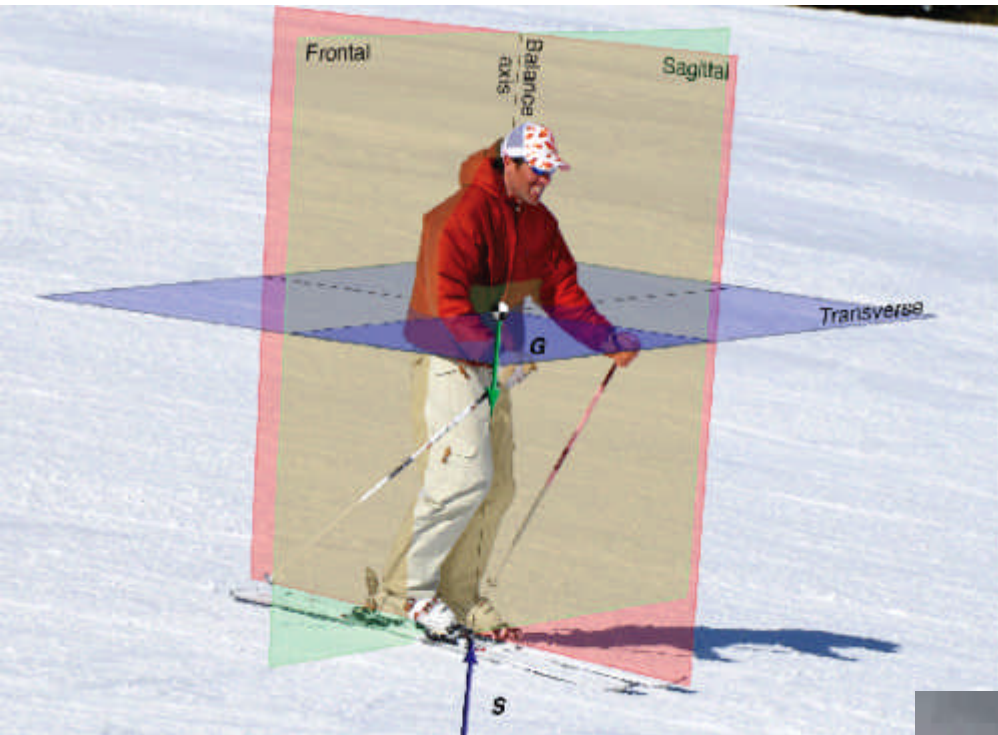


Forgatónyomaték a tömegközéppontra
Az ugró a szagittális síkban elfordul

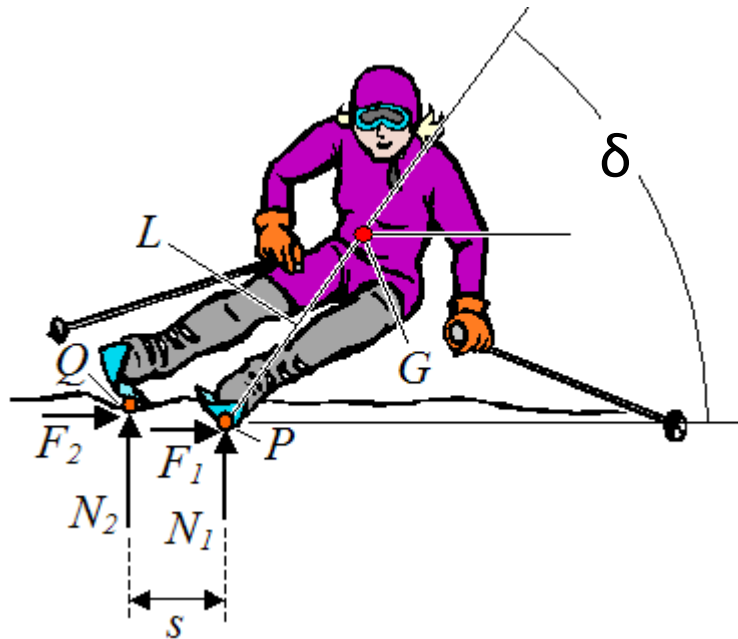
Síelés



Vonatkoztatási síkok



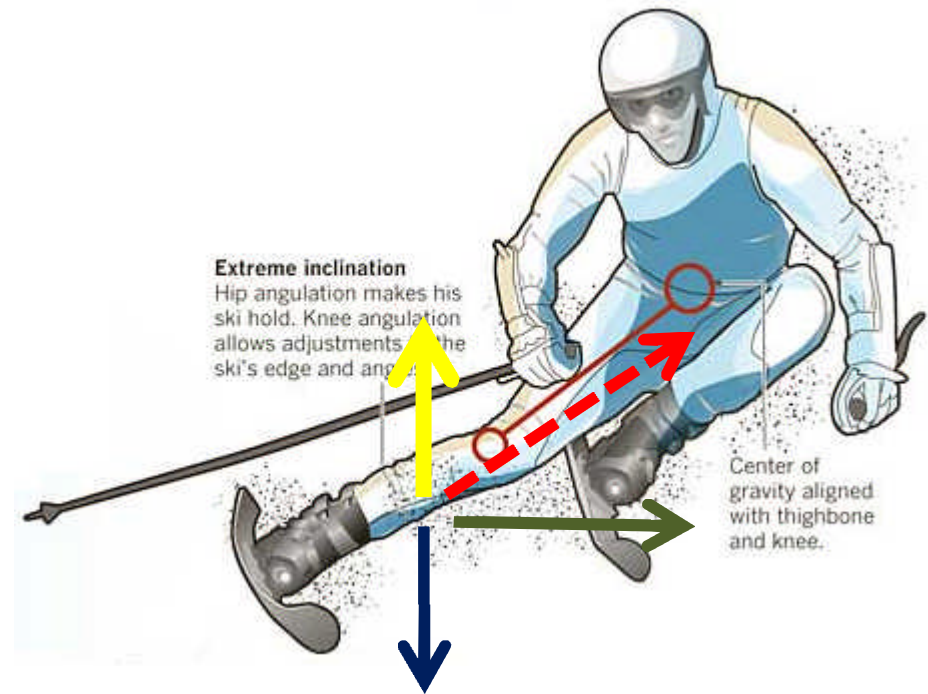
Síelőre ható erők



Ha $\delta=25^\circ$, $v=100\text{km/h}$

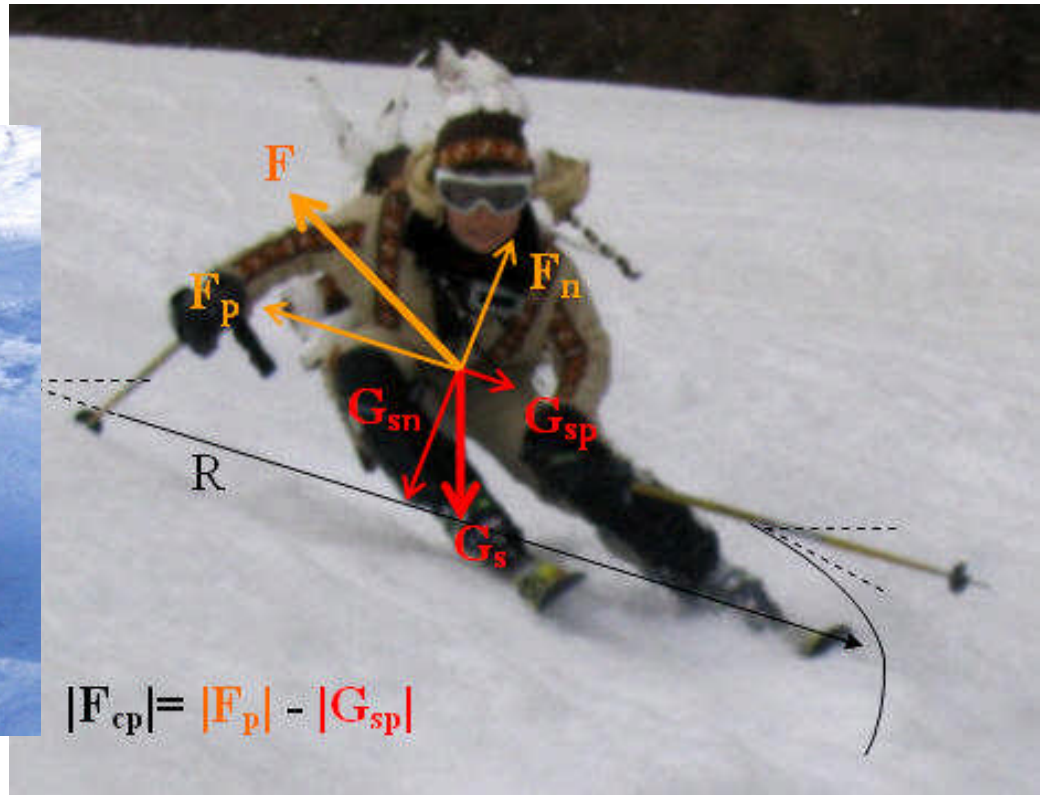
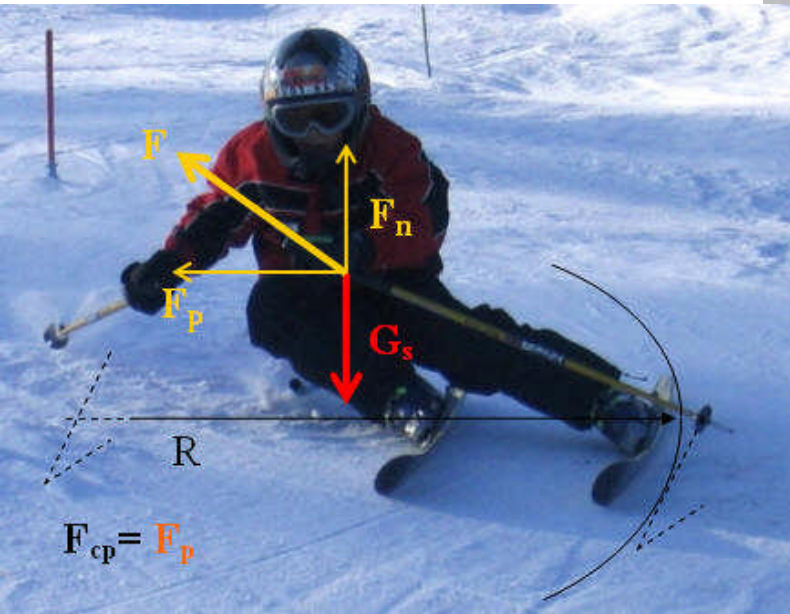
$$F_{reakc} = F_{cp} = \frac{mg}{\text{tg}\delta} = m \frac{v^2}{r}$$

$$r = \frac{v^2 \text{tg}\delta}{g} = 36\text{m}$$

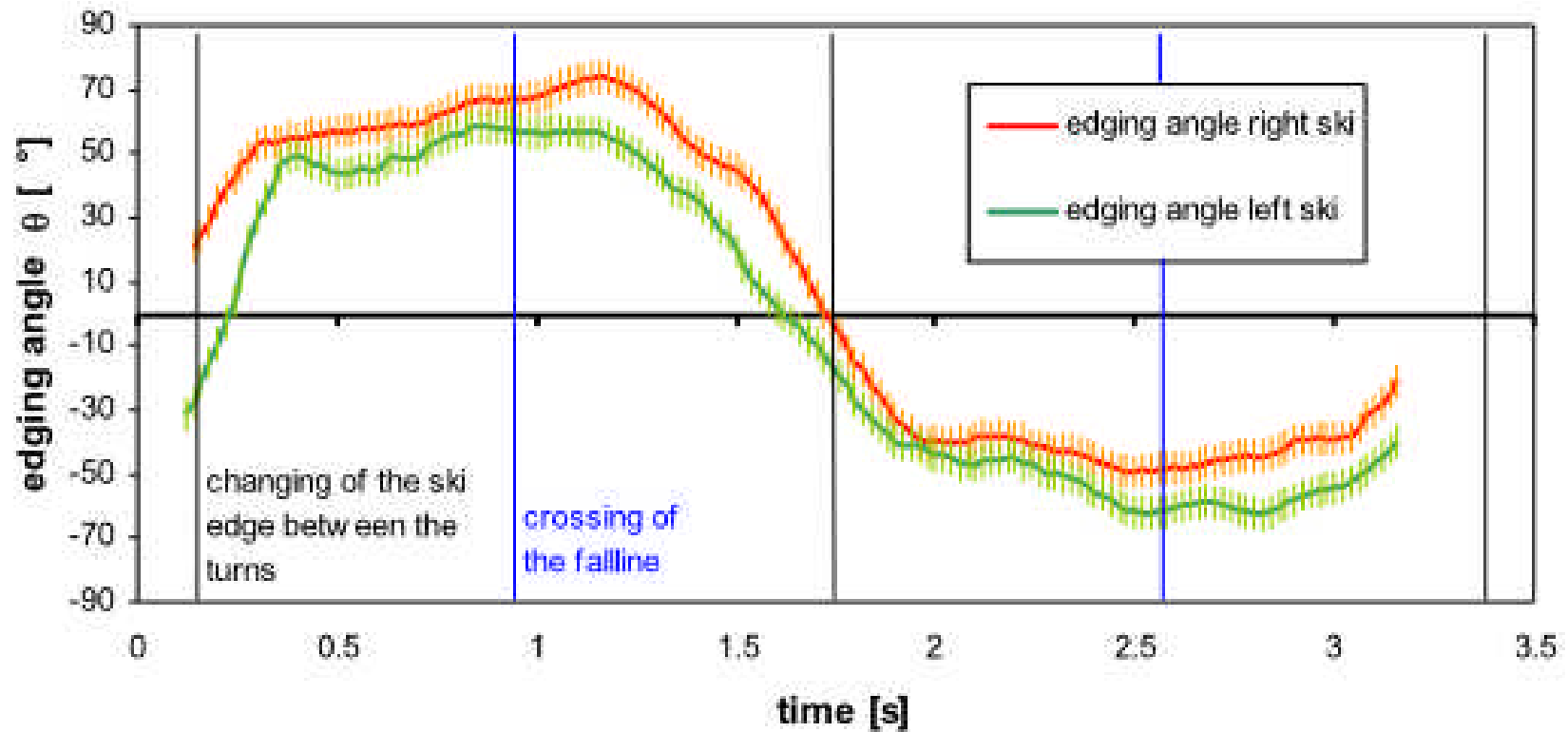


$$F_e = \frac{mg}{\sin\delta} = 2.36 * mg$$

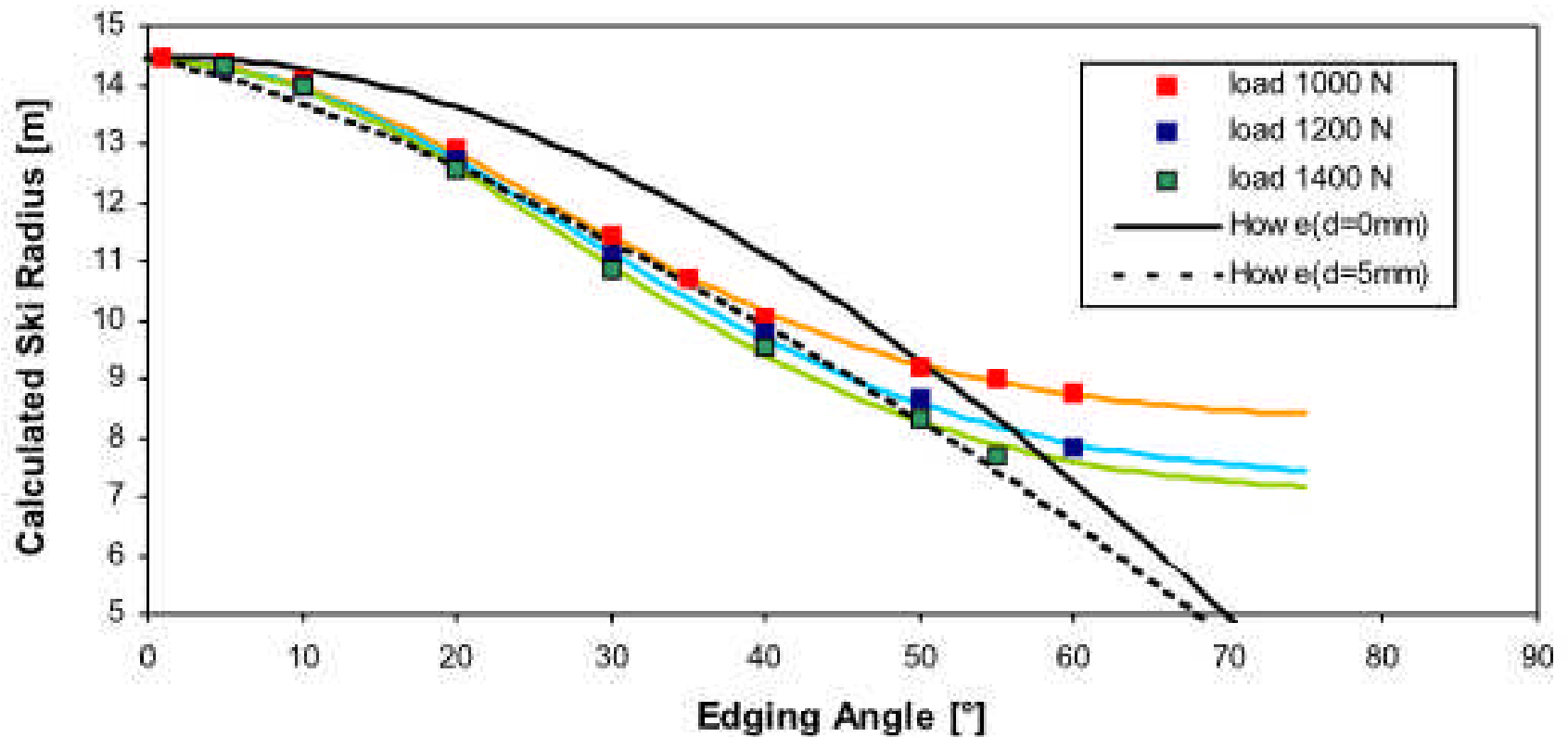
Erőhatások lejtőn kanyarodáskor



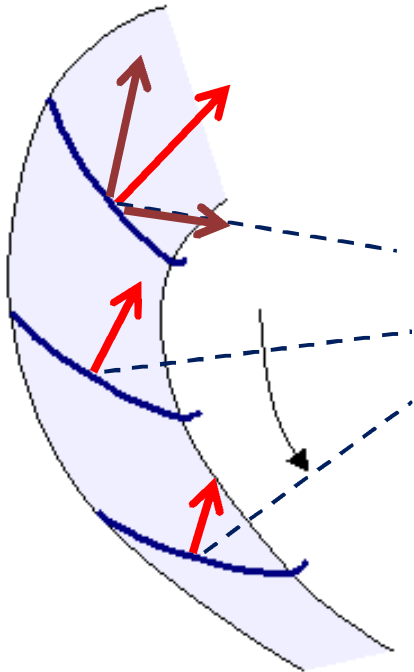
Sílec dőlésszöge kanyarodáskor



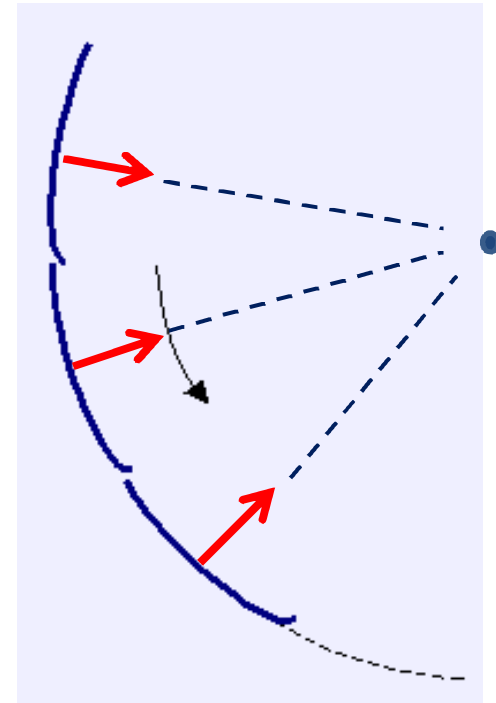
Carving sí fordulókör sugár a terhelés és a dőlésszög függvényében



Miért gyorsabb a carving léc mint az alpin léc?

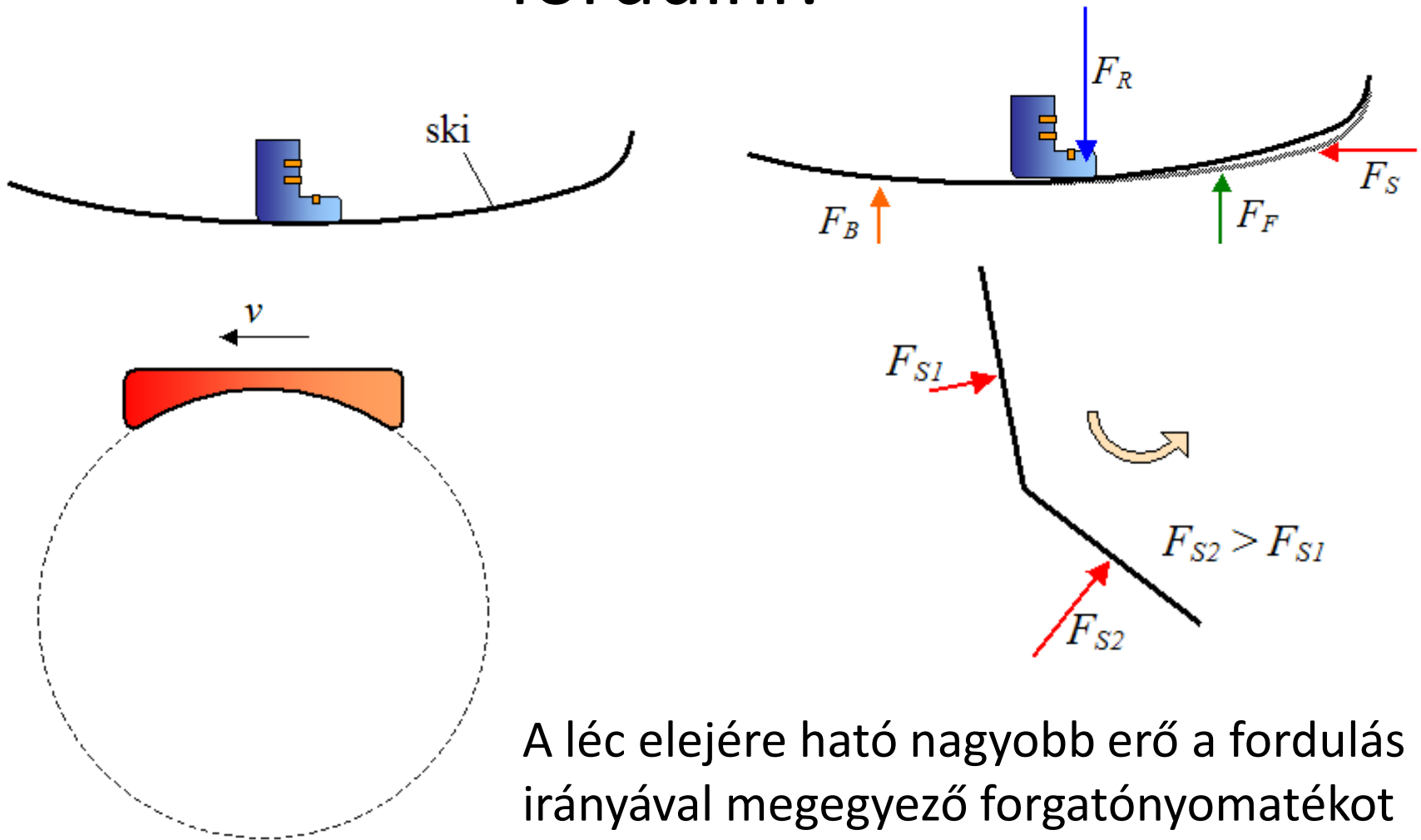


A lécre merőleges reakcióerőnek van tangenciális komponense, ez lassítja a sízőt



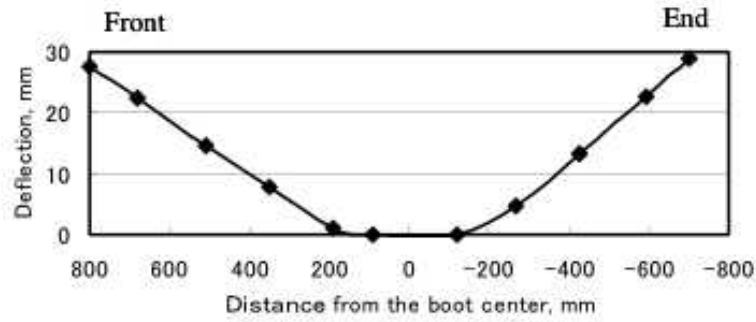
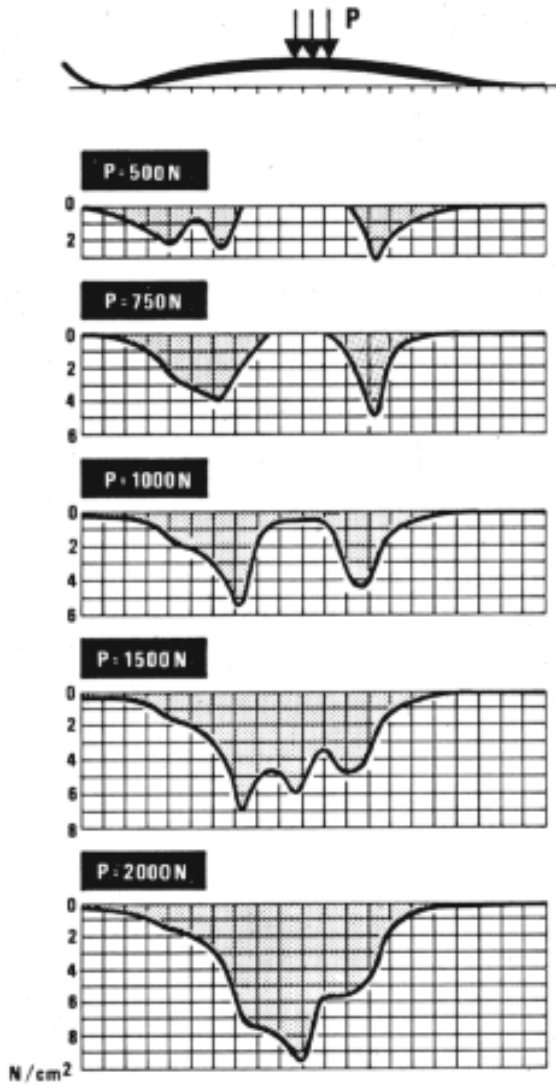
Nincs érintőirányú komponens, a reakcióerő a középpont felé mutat

Miért könnyű a carving lécekkel fordulni?

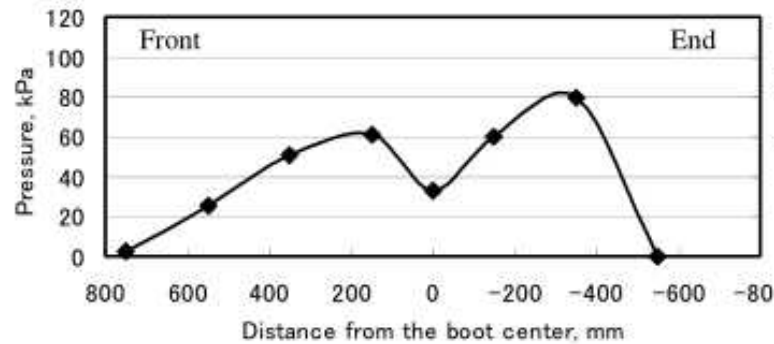


A léc elejére ható nagyobb erő a fordulás irányával megegyező forgatónyomatékokot hoz létre

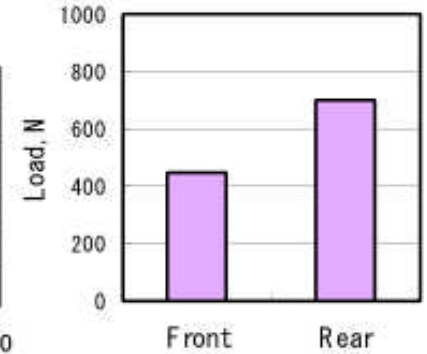
Sílécre ható erő és a lécc deformációja



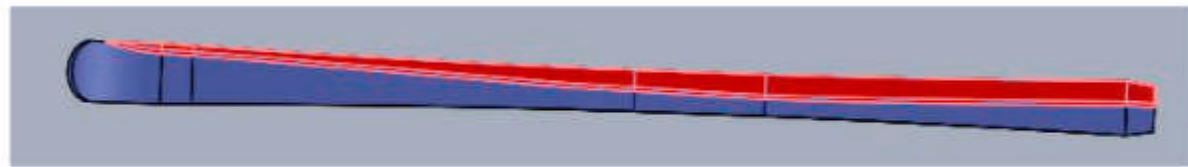
(a) Ski deflection



(b) Pressure distribution



(c) Loads from the plate



Contacting area between ski and snow

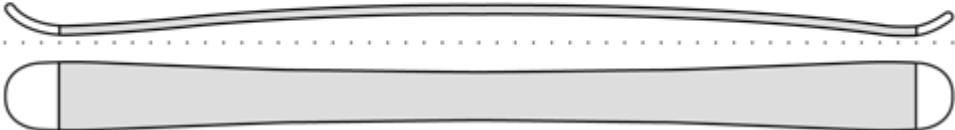
Investigation on the ski-snow interaction in a carved turn based on the actual measurement
 Takeshi Yoneyama (2010)

Carving evolúció



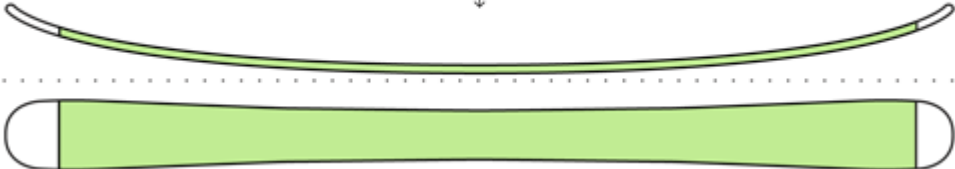
Classic - Camber

CAMBER
↓

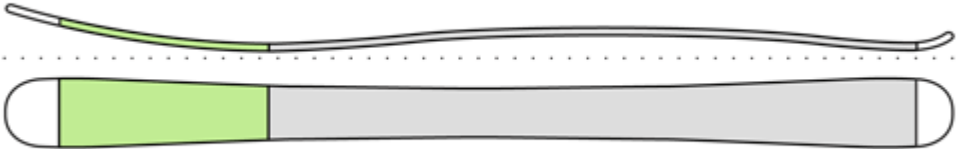


Rocker

ROCKER
↓



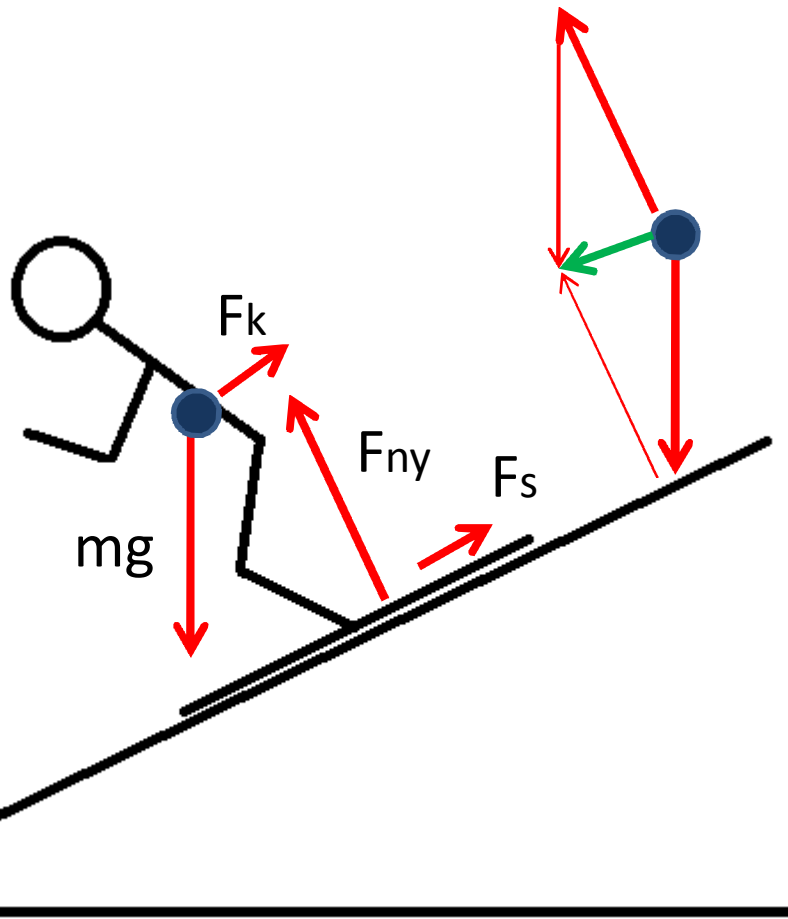
CAMBER
↓



↑
ROCKER

Hibrid (Rocker-Camber)

Nehezebb személy gyorsabban síel?



$$F_L = mg \sin(\alpha)$$

$$F_{ny} = mg \cos(\alpha)$$

$$F_s = \mu mg \cos(\alpha)$$

$$F_k = \frac{1}{2} kCAv^2$$

$$ma = F_L - F_k - F_s$$

Ha $v = \text{áll} \Rightarrow a = 0$

$$F_k = F_L - F_s$$

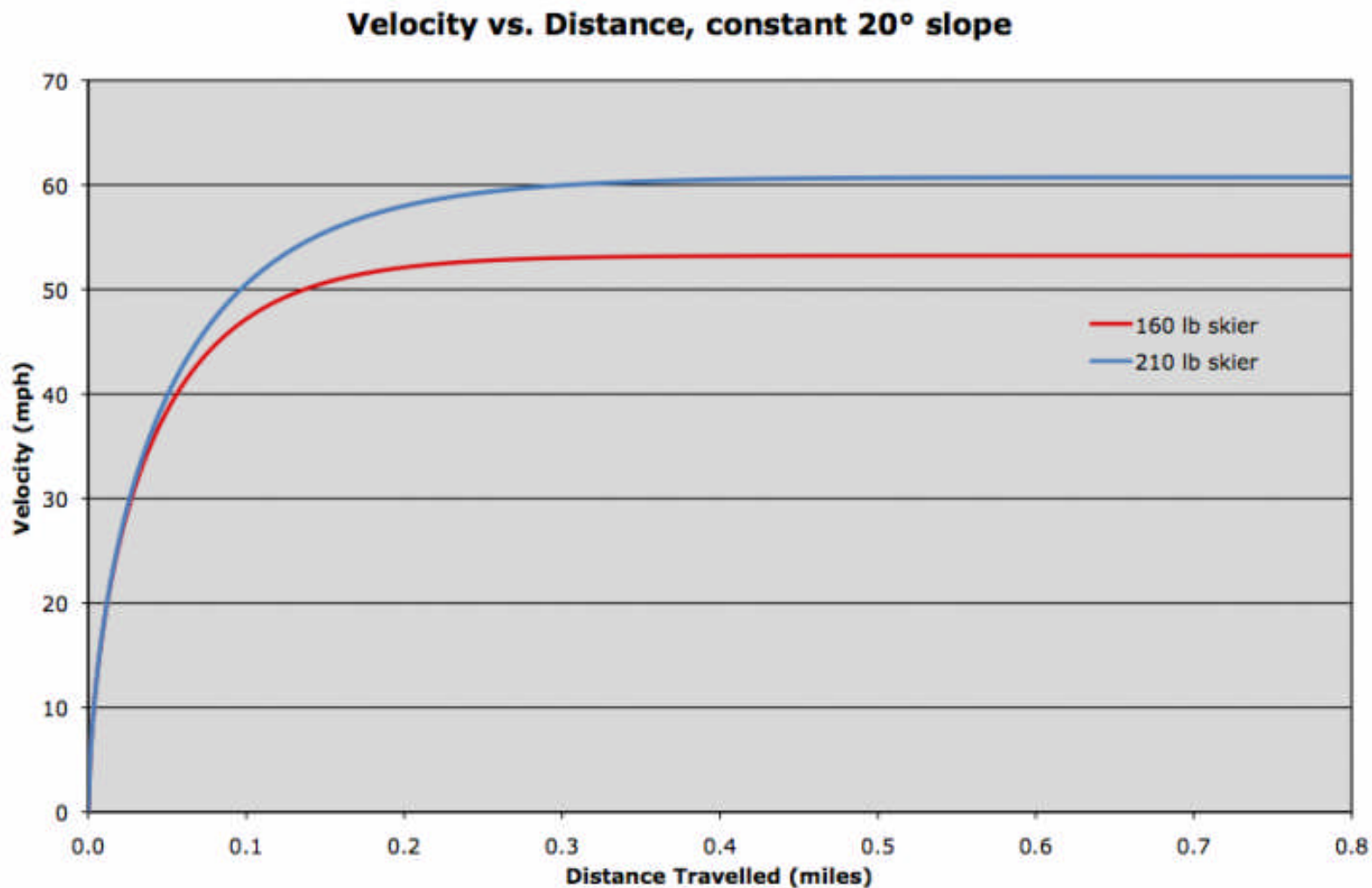
$$\frac{1}{2} kCAv^2 = mg \sin(\alpha) - \mu mg \cos(\alpha)$$

$$v = \sqrt{\frac{2mg \sin(\alpha) - 2\mu mg \cos(\alpha)}{kCA}}$$

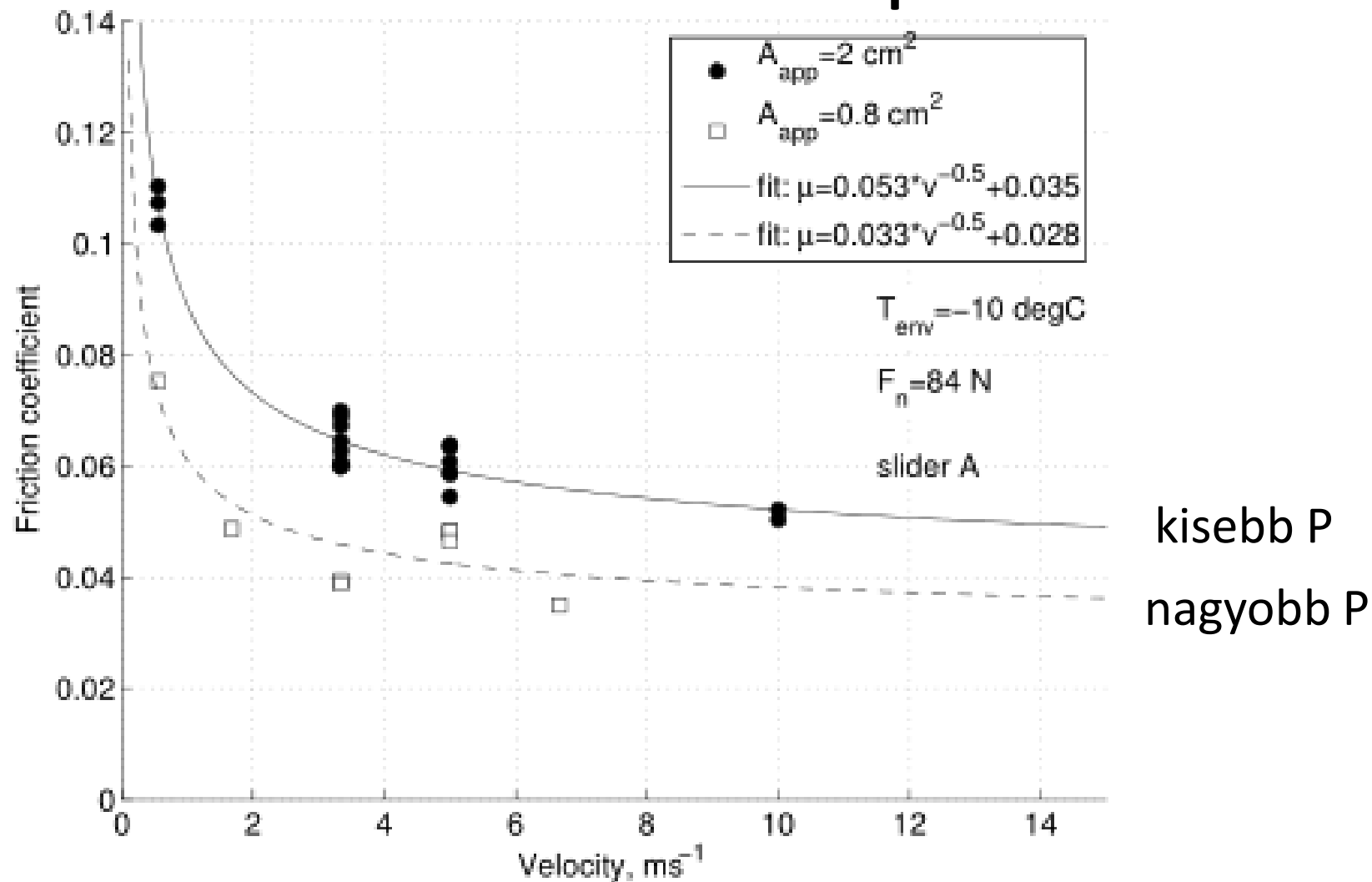
$$v \sim \sqrt{\frac{m}{A}}$$

(kétszerakkora magasság-négyszerakkora A -nyolcszorakkora m) \rightarrow nagyobb m gyorsabb)

Tömeg és sebesség kapcsolata



Felület és súrlódás kapcsolata



Nagyobb nyomás \Rightarrow kisebb súrlódási együttható

Légellenállás

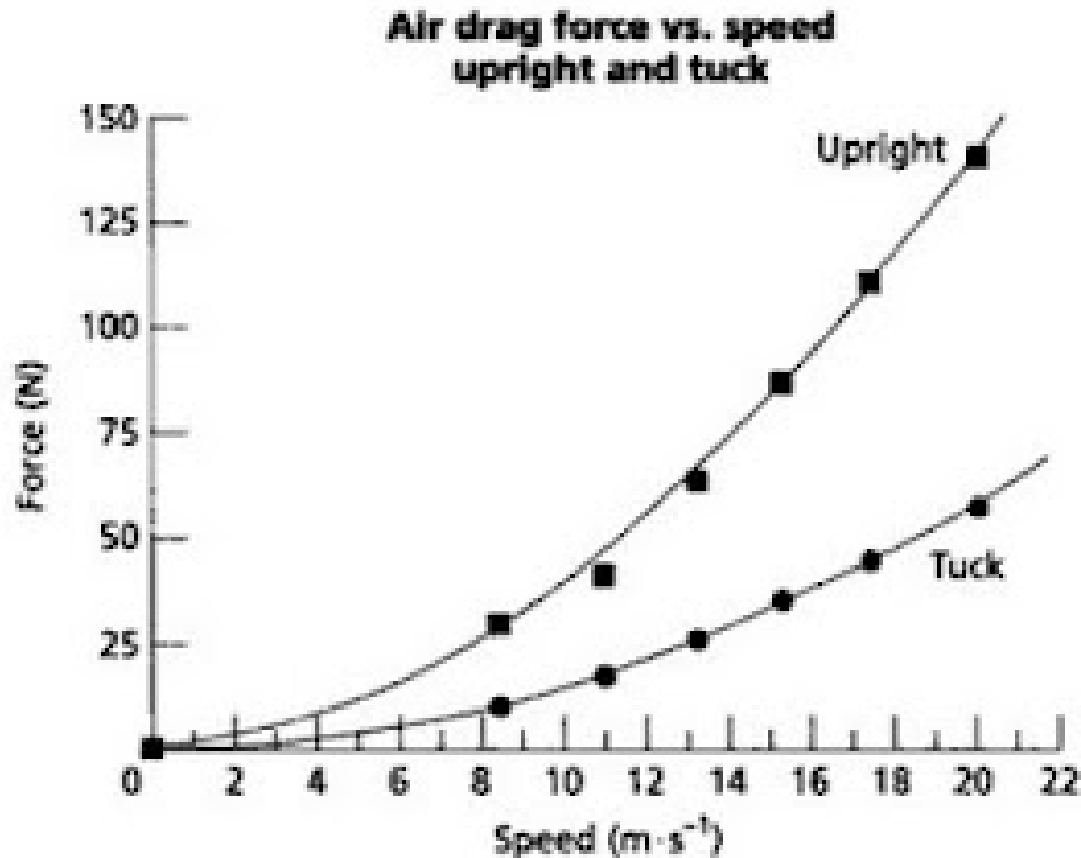
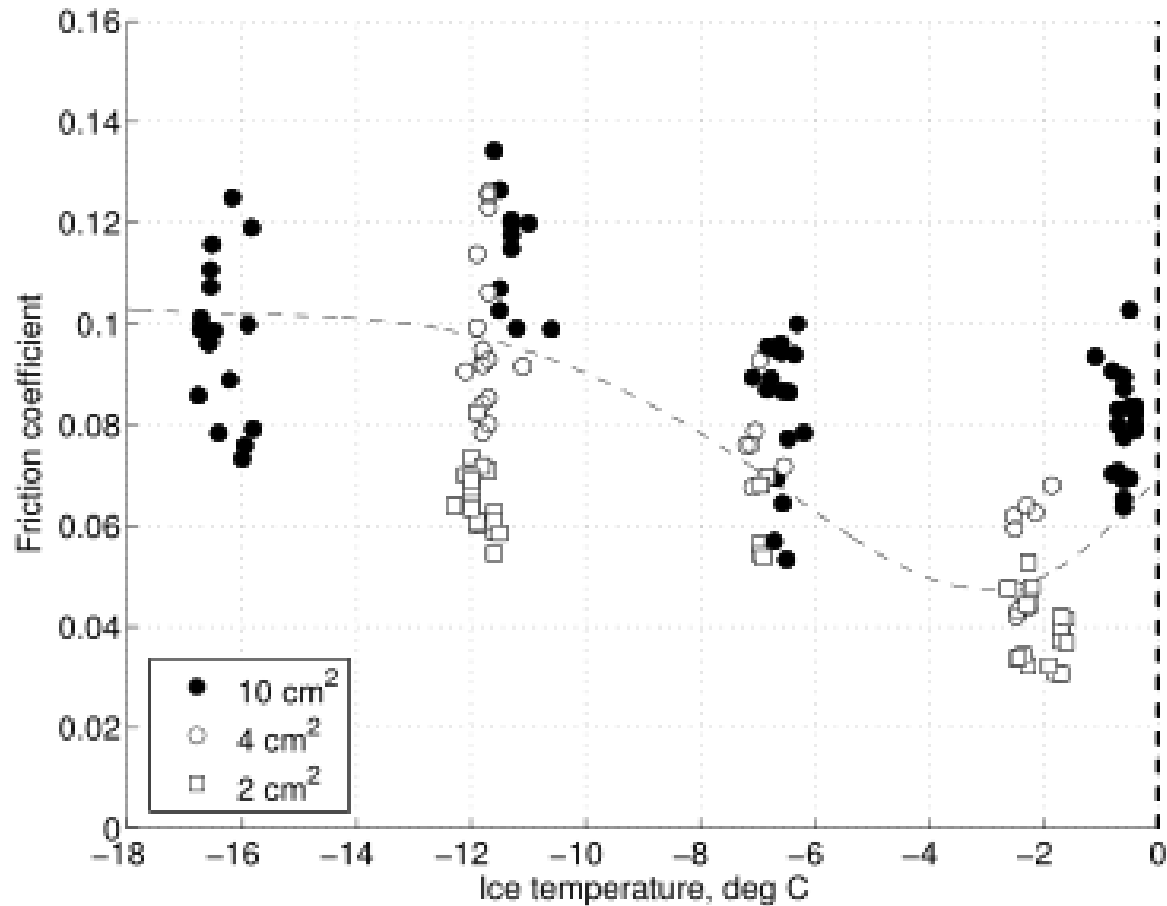


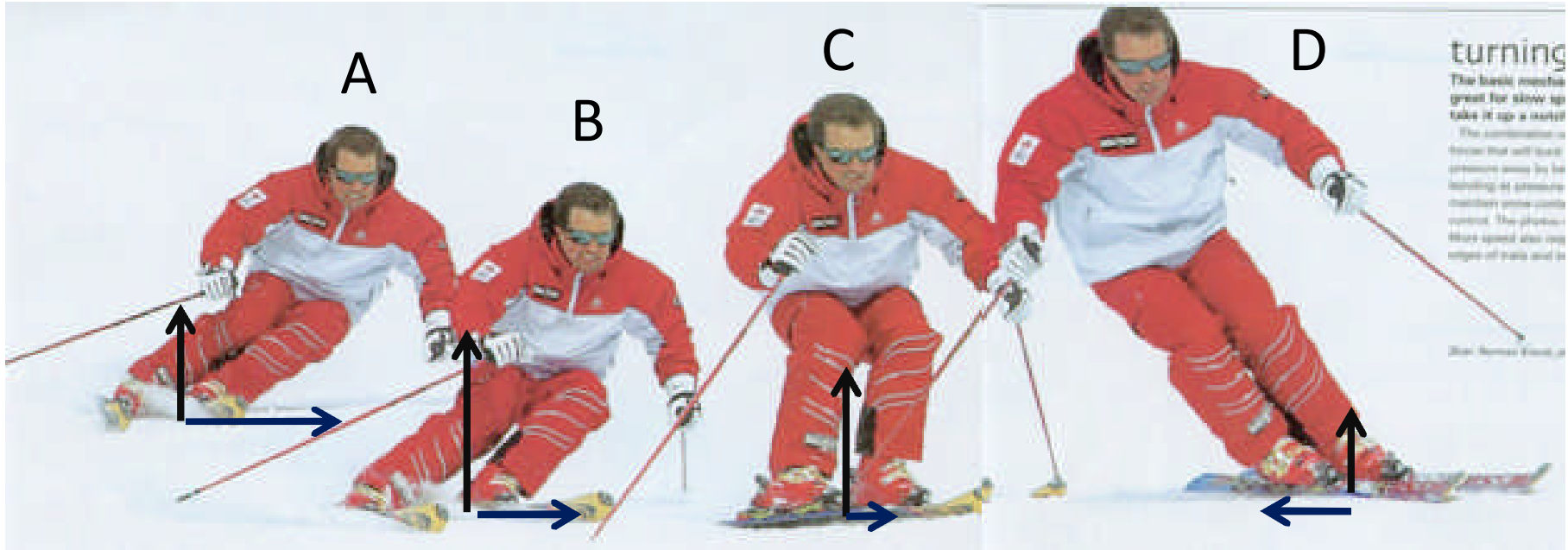
Fig. 12.11 Air drag force vs. speed for various skier positions. Wind tunnel testing of skier positioning showed that drag force is substantially different for tucked positions in comparison to more upright postures. (Data from Svensson 1994.)

Hó súrlódási együtthatója



Súrlódási együttható különböző hőmérsékleteken

Kanyarodás fázisai



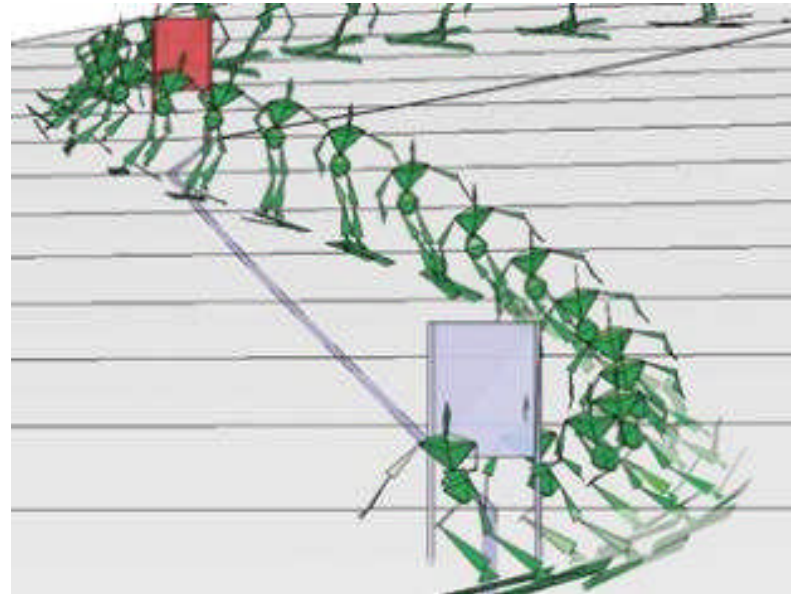
A - Kanyarodás, nagy oldalirányú erő, lécs behajlása maximális

B - Függőleges erőkomponens megnő, TKP emelkedik

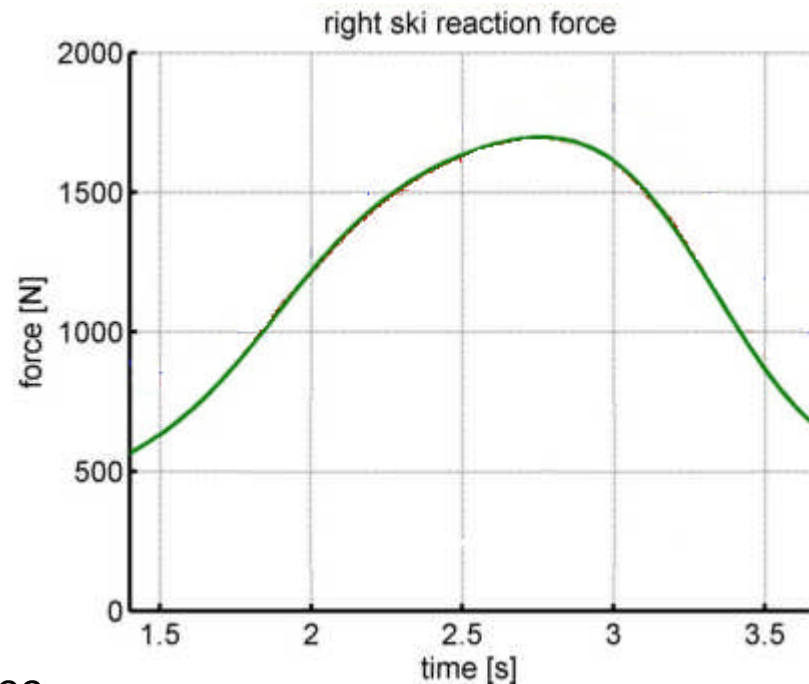
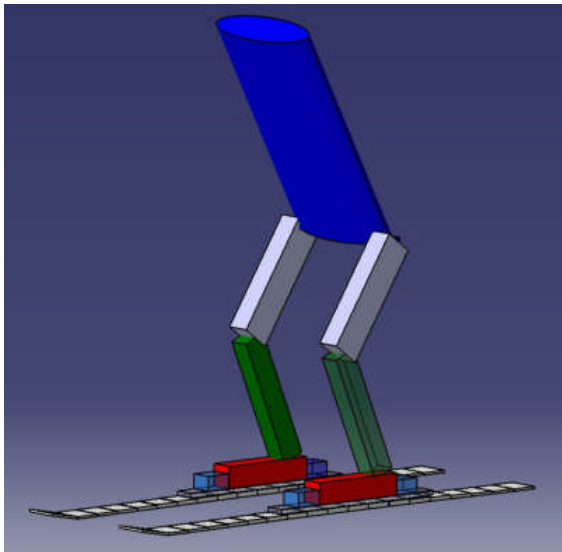
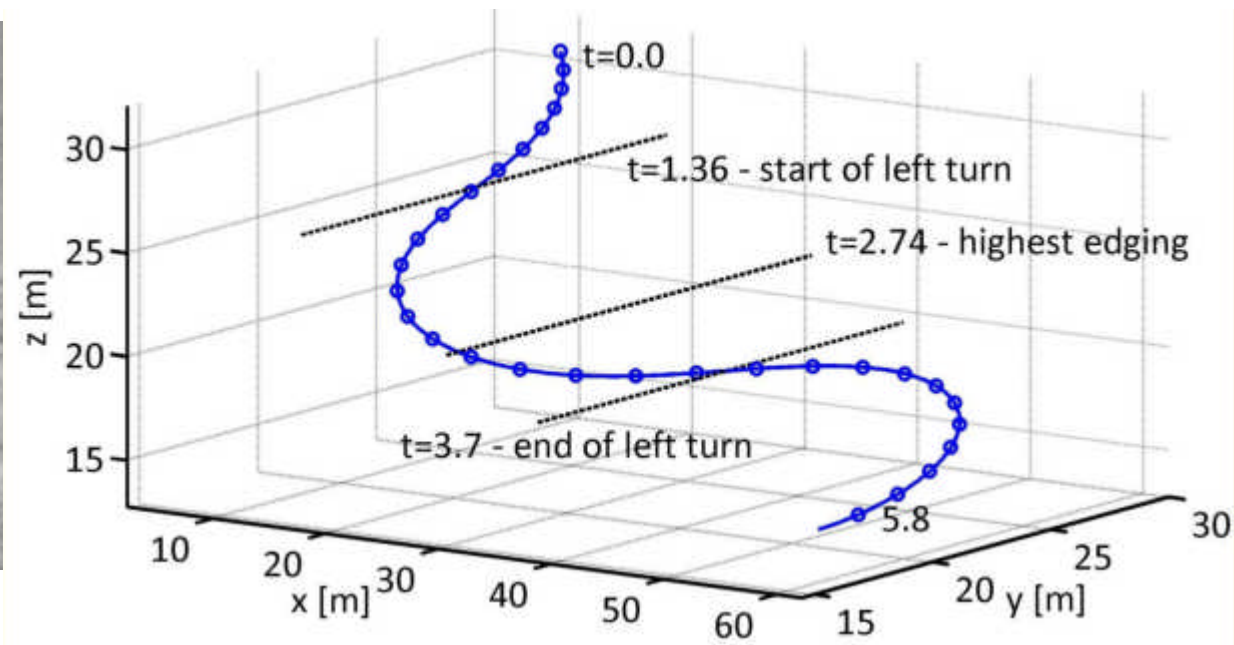
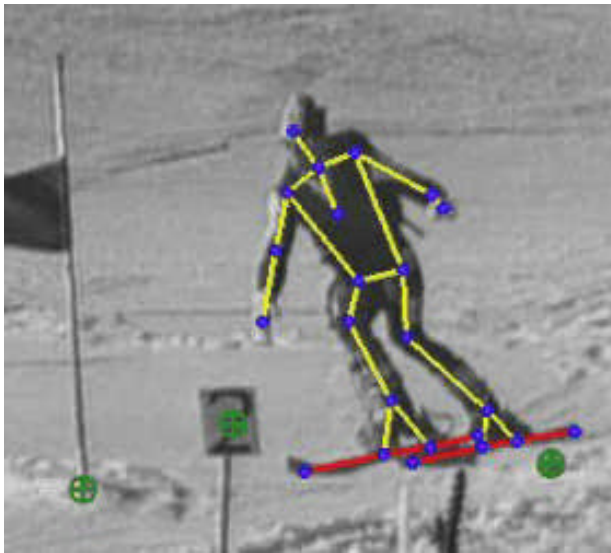
C - TKP tovább emelkedik, lécs deformációja megszűnik

D – TKP lefelé mozdul el, lécs függőleges terhelése csökken, majd ahogy TKP függőleges elmozdulása lassul, lécs deformációja megnő

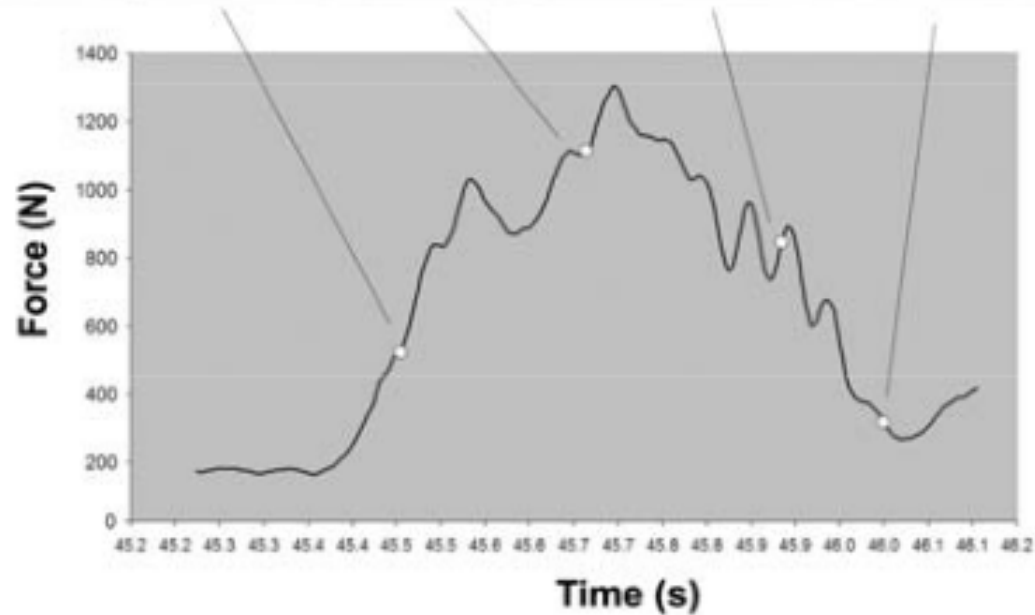
Mozgáselemzés



A kanyarodás során a lécs behajlik \Rightarrow rugalmas energia tárolódik

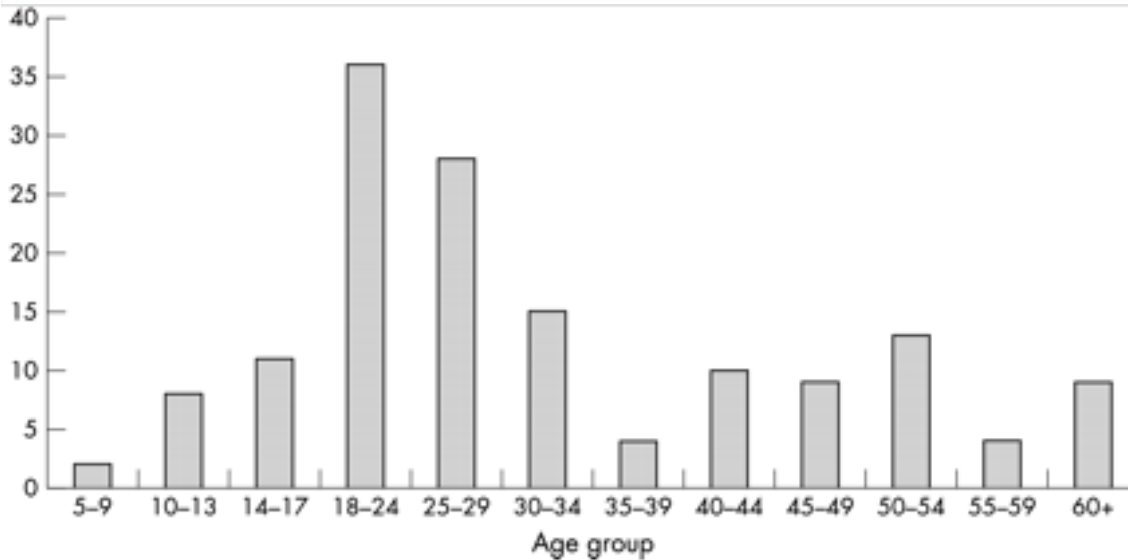
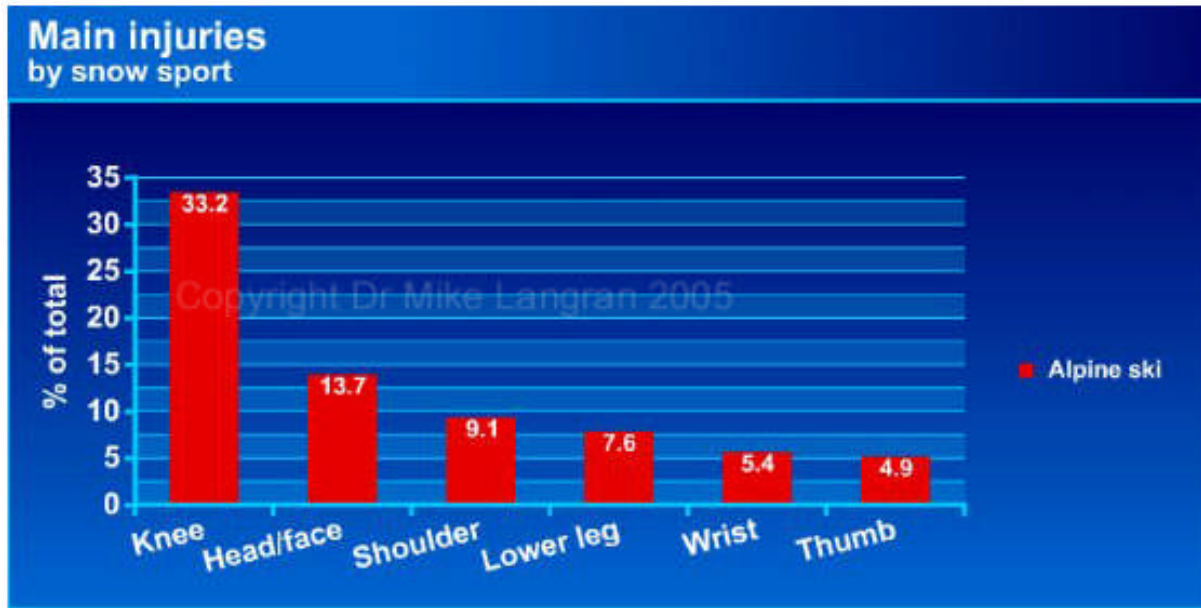


Reaction Forces and Moments in Carved Turns. U Filippi et al. 2009



	Foot	Time s	Max GRF s	Max GRF N	Mean GRF N
Skier A	Outer	0.76±.09	0.39 ± 0.16	1322 ± 157	752 ± 144
	Inner		0.45 ± 0.13	987 ± 186	578 ± 117
Skier B	Outer	0.74±.08	0.42 ± 0.11	1386 ± 173	747 ± 124
	Inner		0.44 ± 0.12	989 ± 225	567 ± 152
Skier C	Outer	0.81±.11	0.45 ± 0.10	1677 ± 216*	947 ± 184*
	Inner		0.46 ± 0.16	1248 ± 224*	586 ± 133

Sérülések



H Xiang. Downhill skiing injury. Inj Prev 2004;10:99-102