The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2234-16

Meeting of Modern Science and School Physics: College for School Teachers of Physics in ICTP

27 April - 3 May, 2011

Physics in sport

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Winter Alpine Physics

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Andrey Varlamov

SPIN-CNR, Rome, Italy

Speed scales

0 50 100 150 200 250 km/h

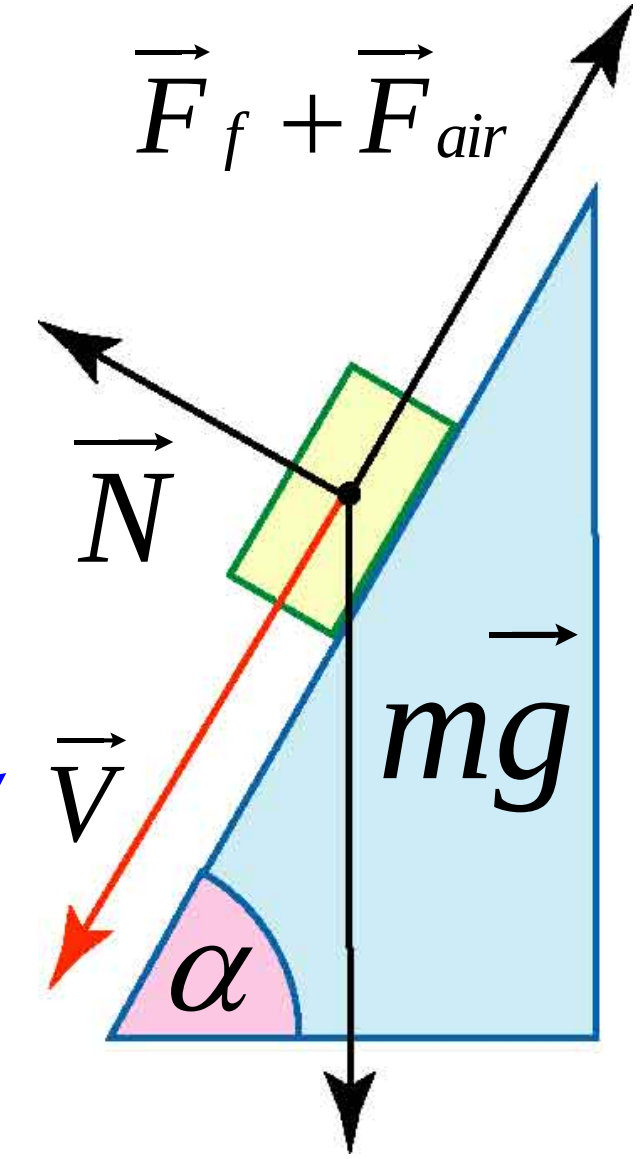
Speed skiing

248.1 km/hr!

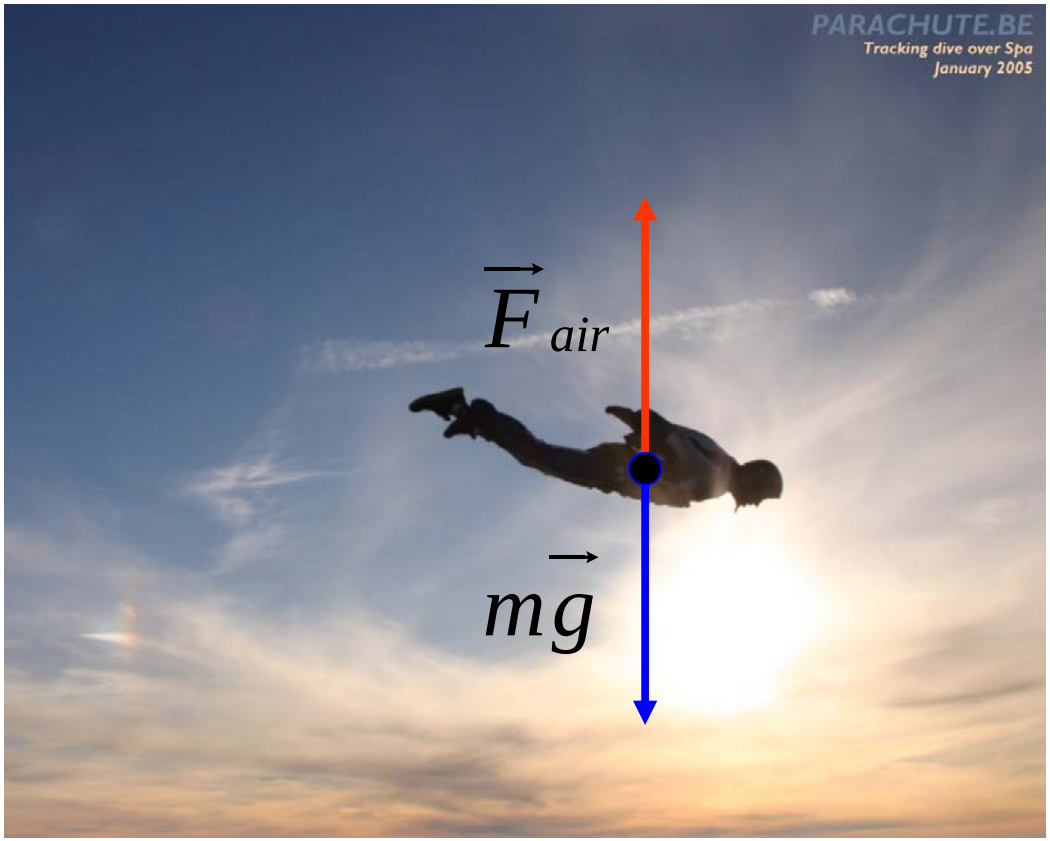
Harry Egger, Austria, 1999.

Monte Rosa glacier under Matterhorn;
Maximum gradient — 62 °

Harry Egger



Physics



Free Fall

$$F_{air} \propto V^2;$$

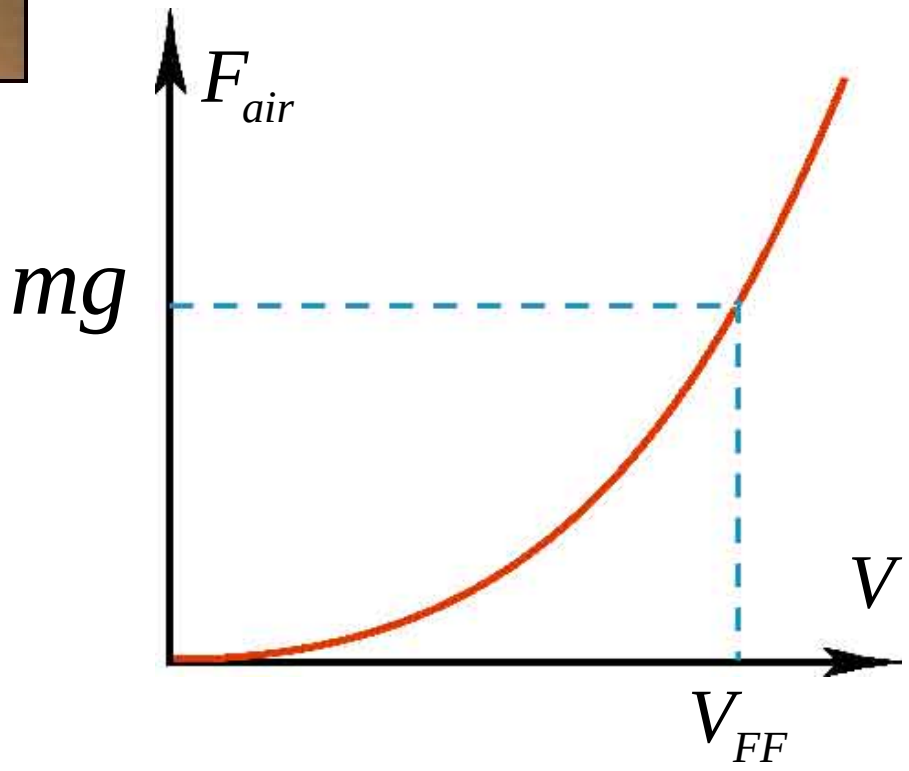
Free fall from 1000 m

Object	**Time**	**Speed (m/s)**	**Speed (km/h)**
Smooth sphere D=0.5 m	15.8 s	~106 m/s	381 km/h
Upright body	16.4 s	~95 m/s	343 km/h
Horizontal body	28.9 s	~37 m/s	135 km/h
Tuck body	23.0 s	~50 m/s	180 km/h

Wind tunnel

$$F_{air} = C_p V^2 = mg$$

$$V = \sqrt{\frac{mg}{C_p}}$$



Physical factors in speed skiing

1. ***Gravity and angle***
2. ***Air drag***
3. ***Friction***

Bobsleigh & Luge

The sport of bobsleigh began at the end of 19th century when the Swiss attached a steering mechanism to a toboggan.

In 1897, the world's first bobsleigh club was founded in St. Moritz, Switzerland.

Eugenio Monti (Italy) won 11 world championships (1957–1968);

Track and speed

Sigulda bob & luge track

Nagano, 1998,
4-man event

$$V_{average} \sim 115\, km/h;$$

$$V_{\max} \leq 230\, km/h!$$

Addends of victory

Push

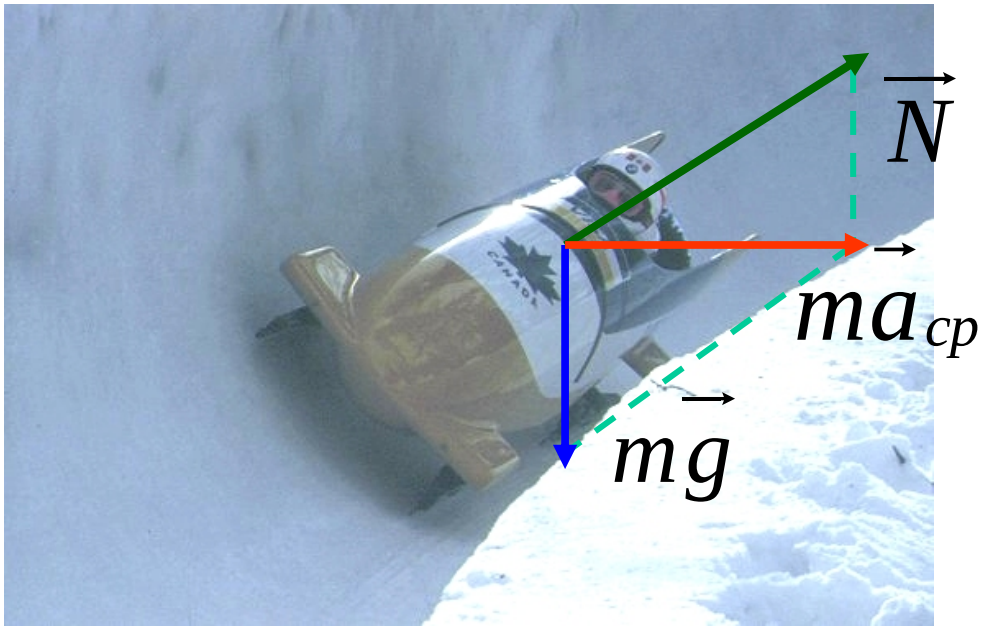
Ride

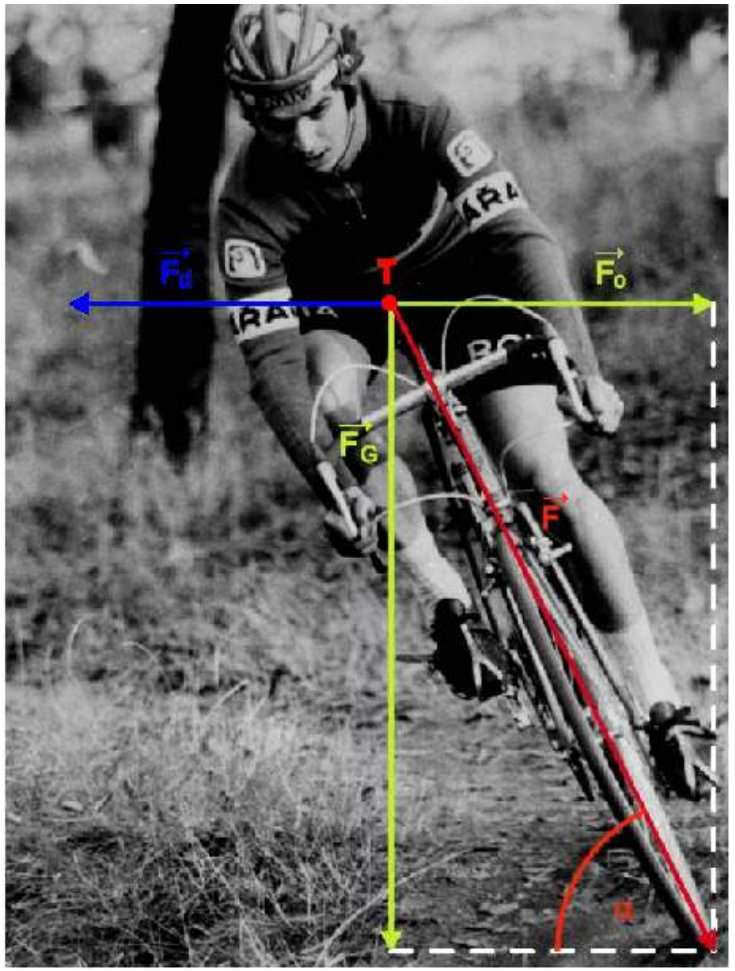
Win!

Centripetal versus centrifugal

Inertial frame

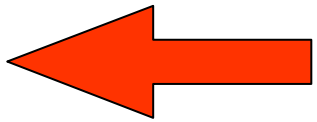
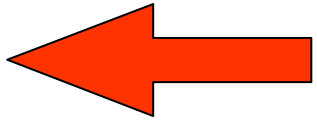
Noninertial frame





$$m\vec{a}_{cp} = m\vec{g} + \vec{N} + \vec{F}_{air}$$

Physical factors in bobsleigh

1. *Initial impulse*  **New!**
2. *Gravity*
3. *Air drag*
4. *Friction*
5. *Optimal trajectory*  **New!**

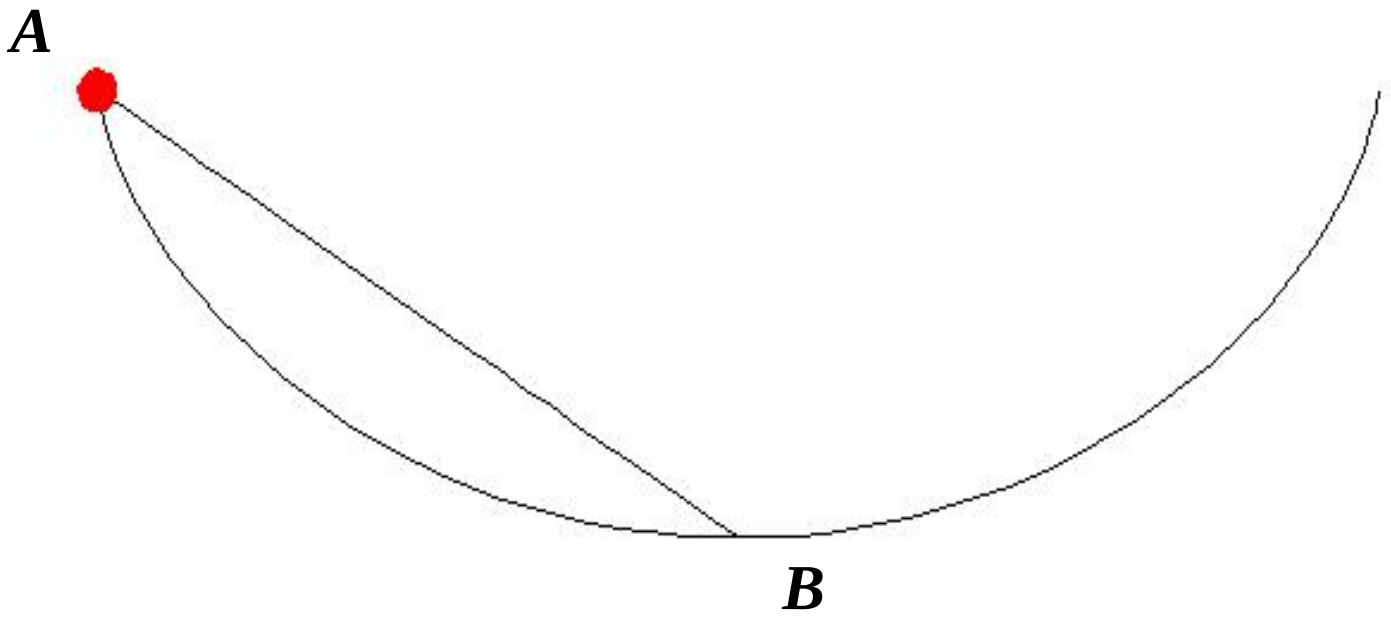
Luge speed record

139.4 km/h

Tony Benshoof

The problem of optimal trajectory

1. What is the fastest way from ***A*** to ***B***?
2. Is the straight way faster?



Brachistochrone

What is the path of quickest descent from ***A*** to ***B?***

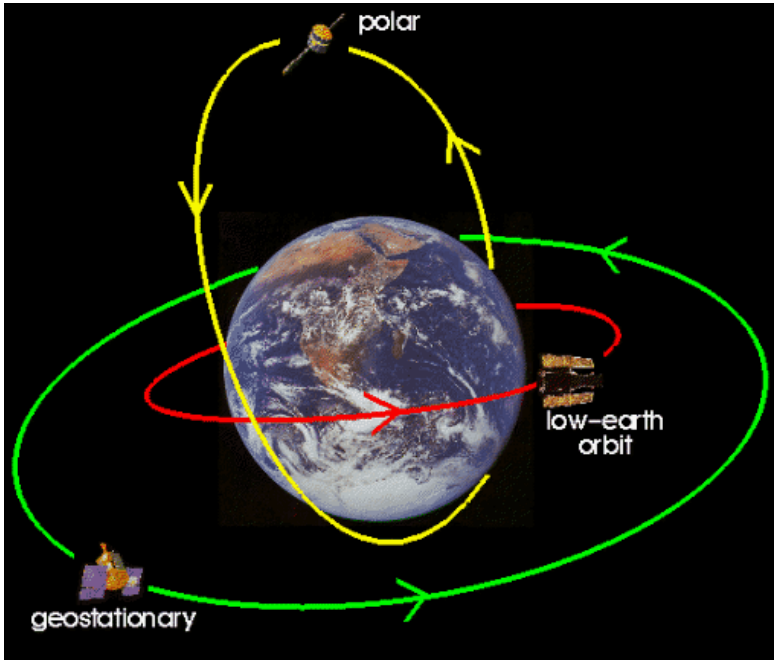
The problem of minimal time

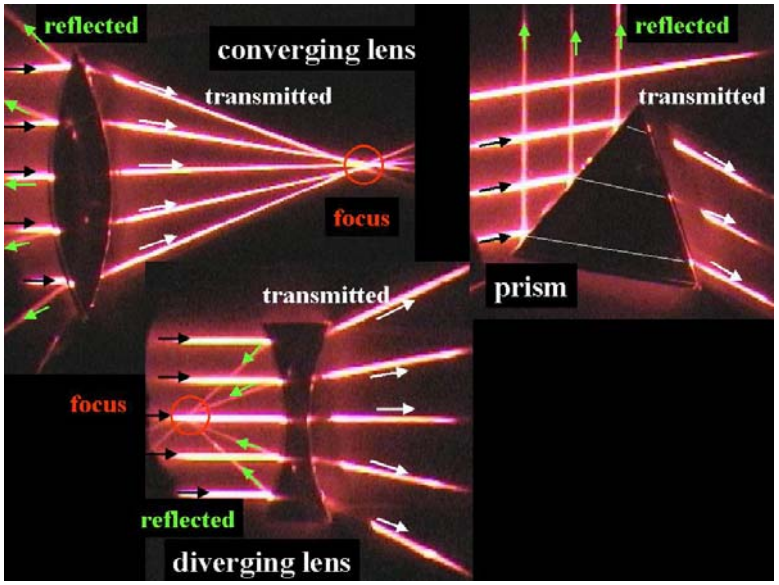
Galileo's hypothesis — the ***circular arc?***

Other minimum principles

Brachistochrone* — *problem of minimal time

Mechanics — Maupertuis' minimal action principle

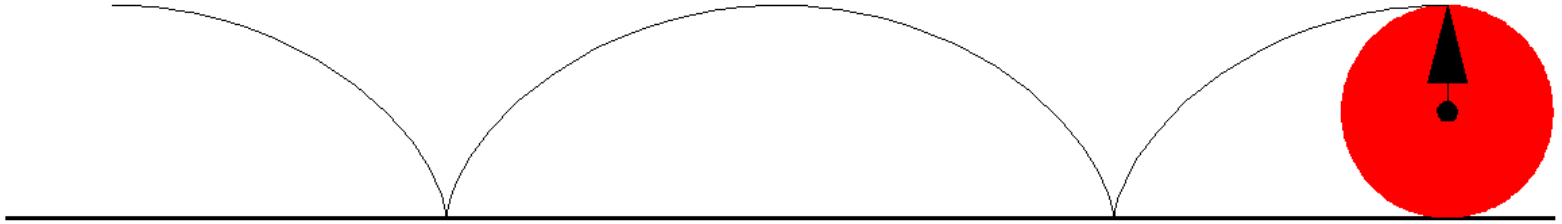




Optics — Fermat's minimal time principle

Cycloid

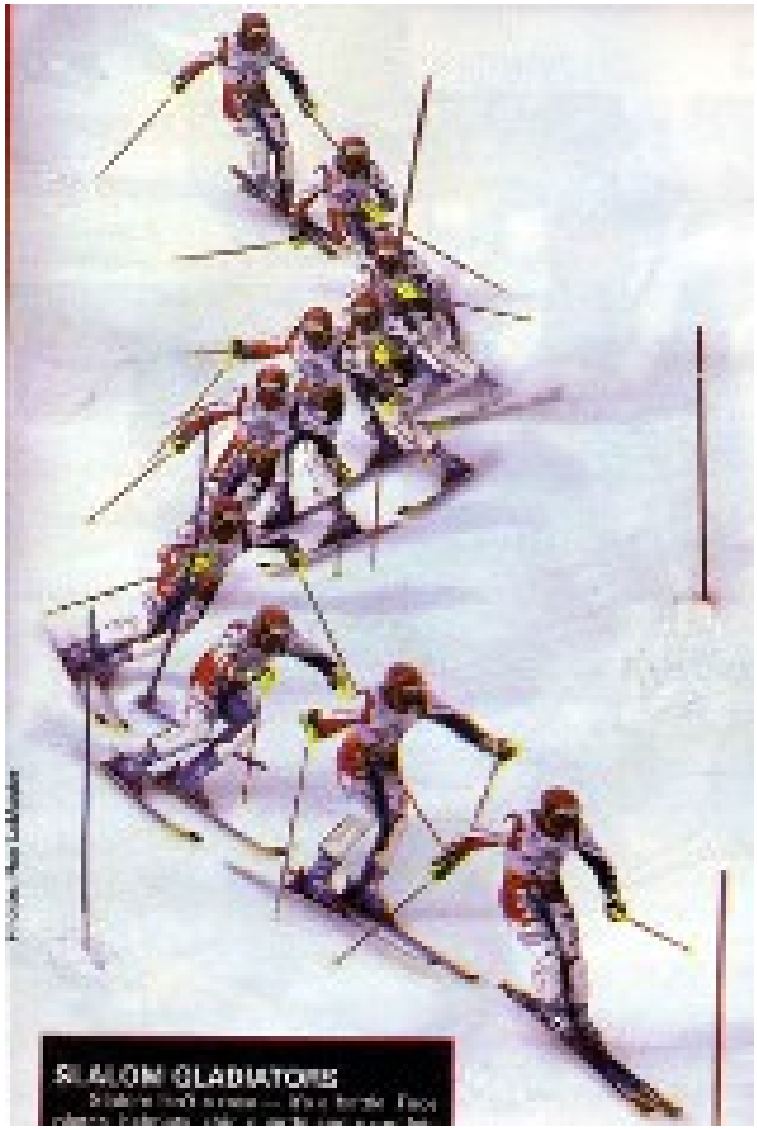
Johann Bernoulli, 1697



Alpine Skiing

Discipline	Speed (km/h)	Speed (m/s)
Downhill Racing	~130 km/h	~30 m/s
Super G	~105 km/h	~29 m/s
Giant Slalom	~75 km/h	~21 m/s
Special Slalom	~ 50 km/h	~14 m/s

Special Slalom



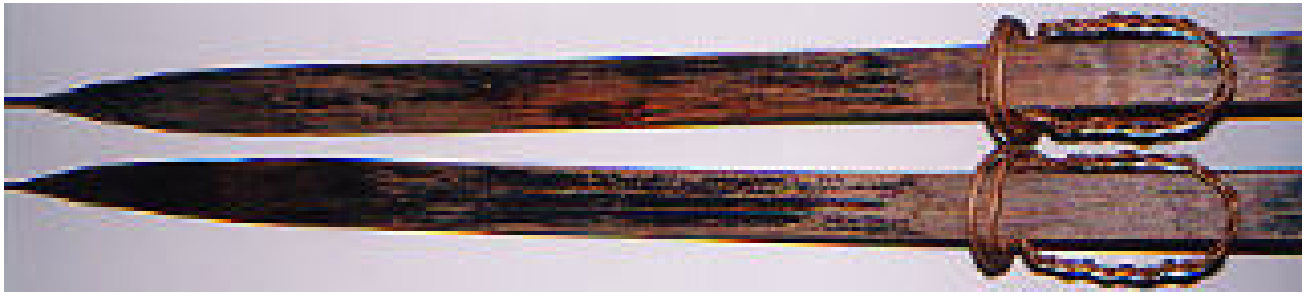
History of skiing

- Cave drawing from Eastern Russia. (between 7000 and 5000 B.C.)

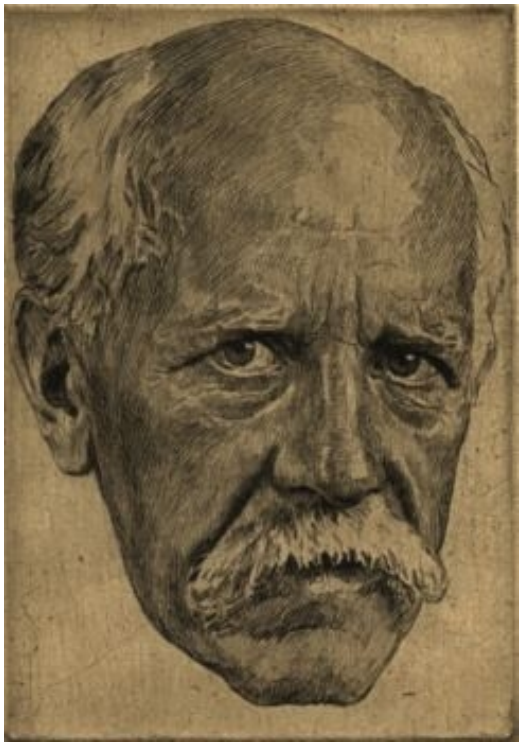
Telemark skis.

Sondre Norheim (Telemark County, Norway, XIX century)

- New skis were shorter (about 2 m 40 cm) than other skis used at that time.



•The bindings were made of twisted willow from birch-roots.



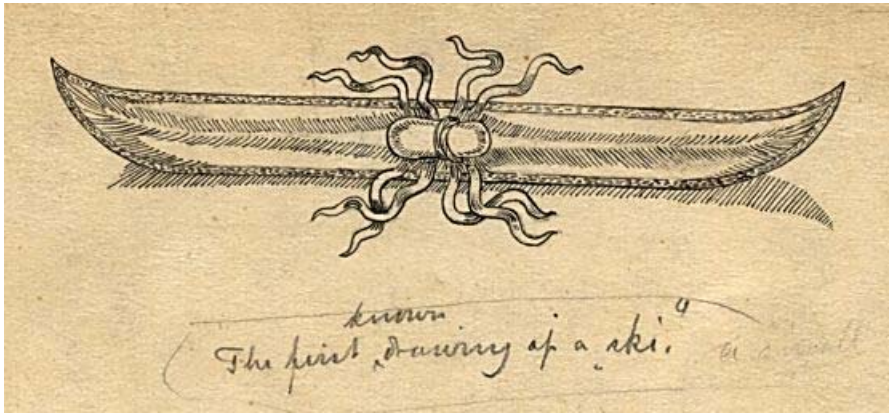
Fridtjof Nansen

Norwegian arctic explorer, zoologist and statesman; Nobel Peace Prize 1922.

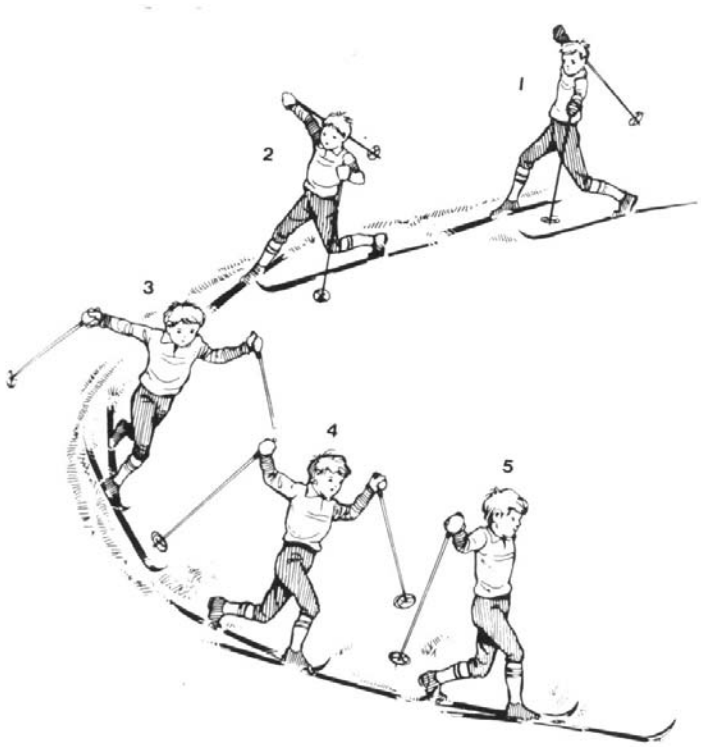
12 times national champion in skiing;
World record for one-mile skating.
The first to cross the mid-Greenland ice cap on skis (1888).

1890 — *book*
On Skis Over Greenland

Nansen Gallery



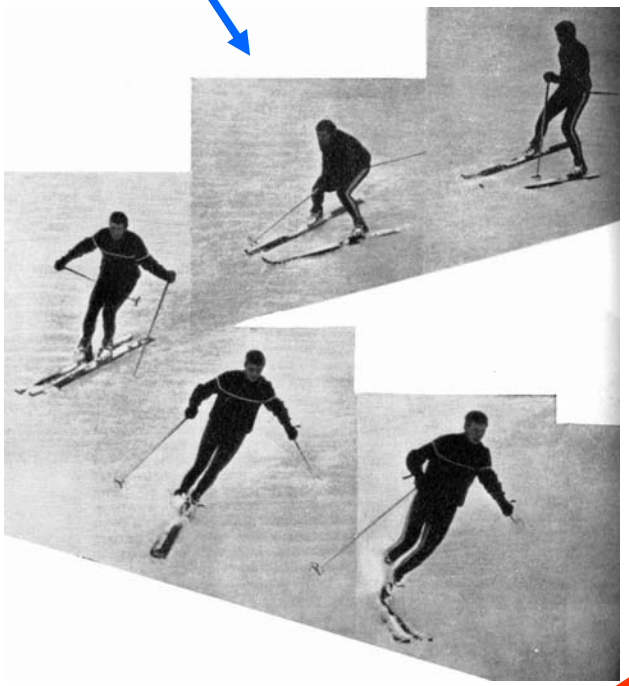
Telemark turn



Basics of alpine skiing

wedge (slow)

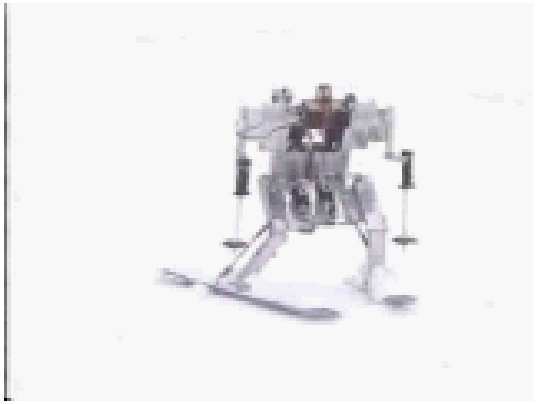
stem (faster)



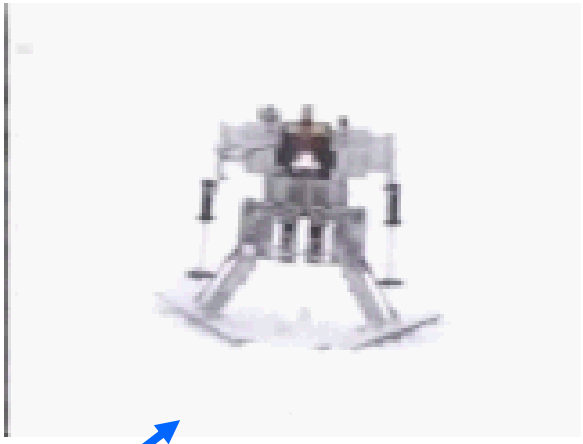
parallel turn — Christiania

Ski robots

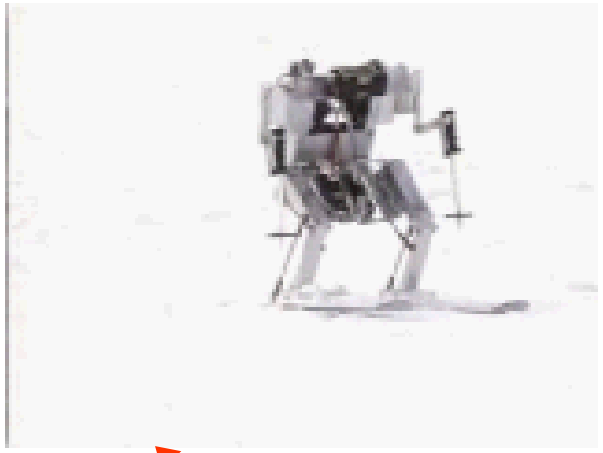
Shiro Shimizu



wedge

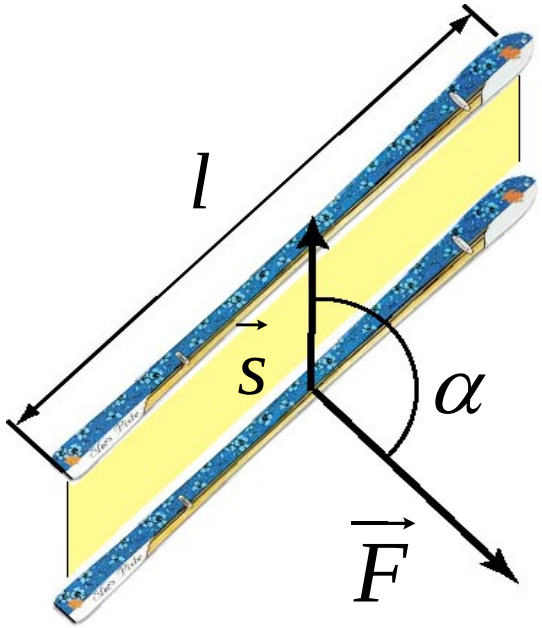


stem



Christiania

Skidding

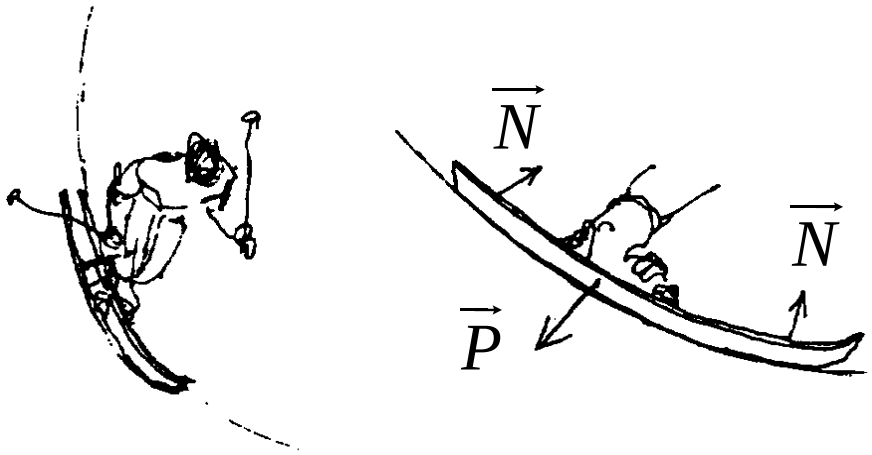


$$A = \vec{F} \cdot \vec{s} = f\, l\, s \cos\alpha = -f \cdot S;$$

$$f = \frac{F}{l}; \qquad A \propto \cos\alpha < 0.$$

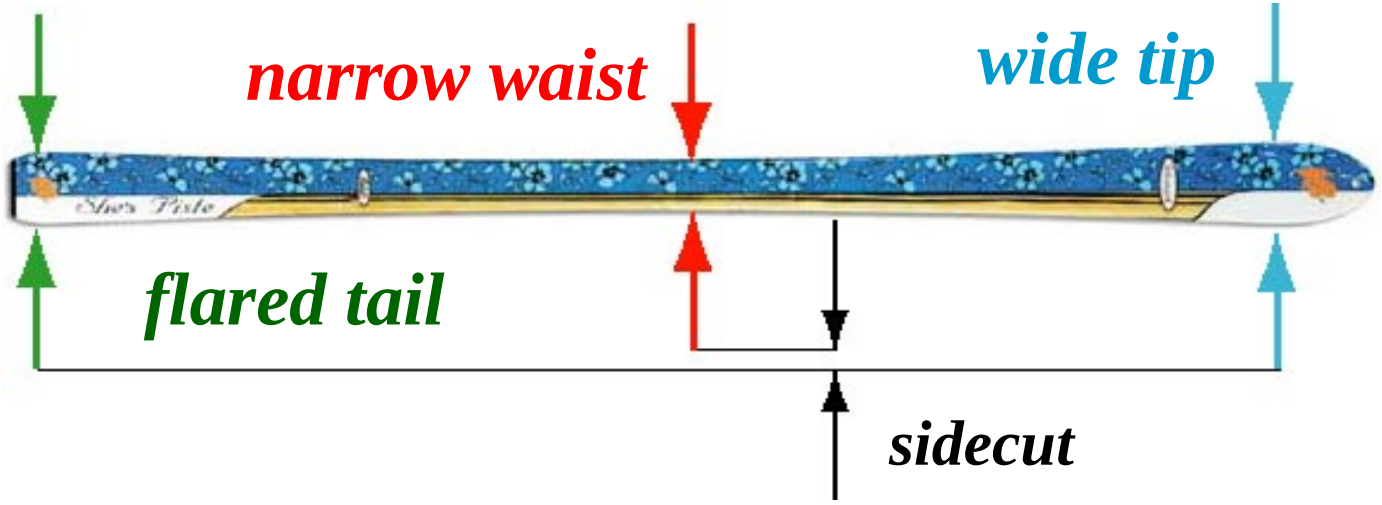
Work against friction A is proportional to swept area S

Carving revolution of 1990-ies



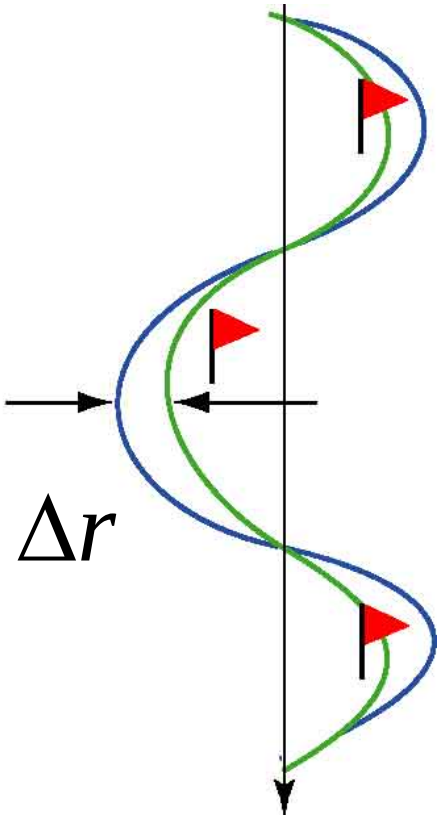
No skidding

- ***Easy to flex***
- ***Hard to twist***
- ***New geometry***



Optimal trajectory

Grenoble, 1968



$v \sim 10\, m/s;$

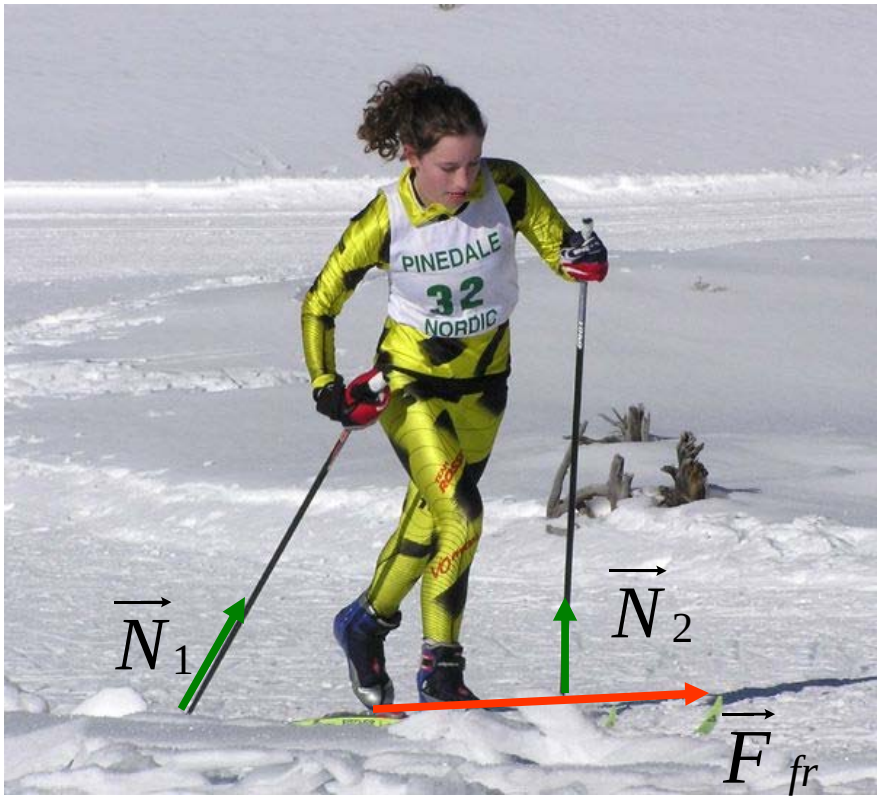
$N \sim 50;$

K.Schranz, Austria

J.Heuga, USA

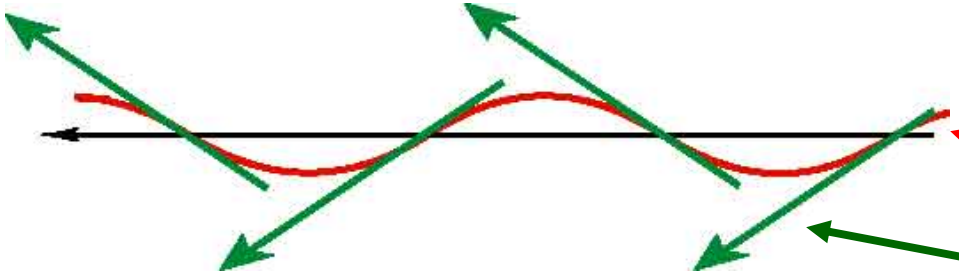
G.Perillat, France

With and without friction



Main propelling force — $\vec{F}_{fr}$

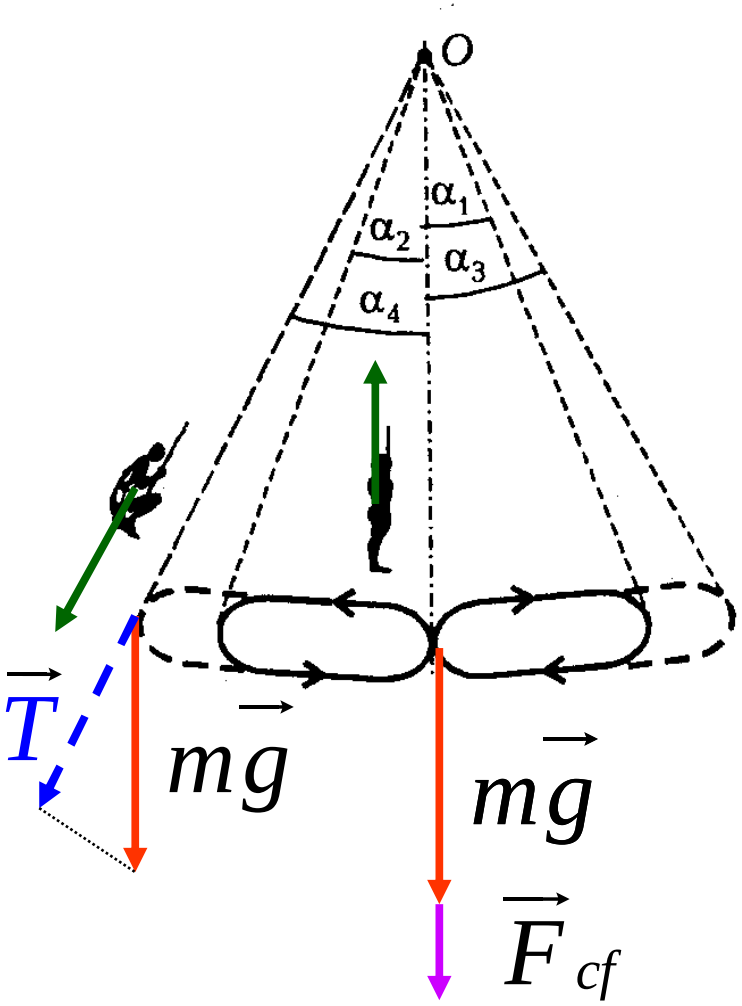
Skiing without friction



center of mass

skis

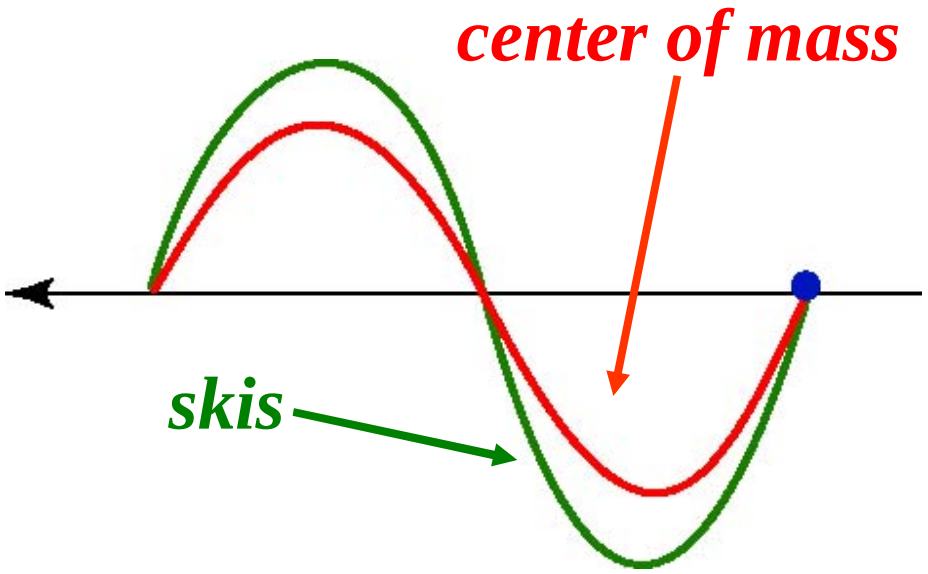
Swing and parametric resonace



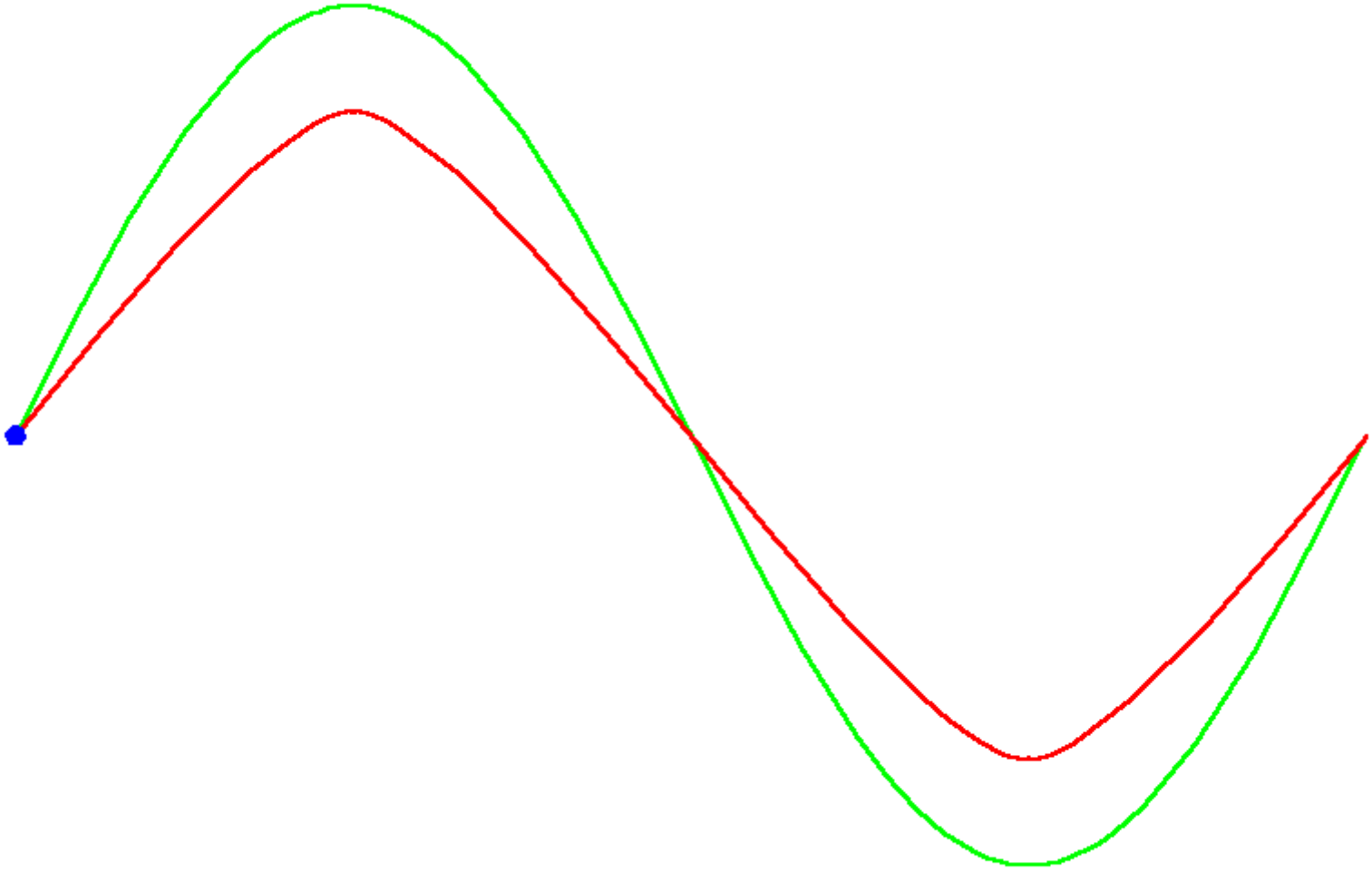
$$mg + F_{cf} > T;$$

$$\Delta E_{cycle} = \Delta A_{cycle} > 0.$$

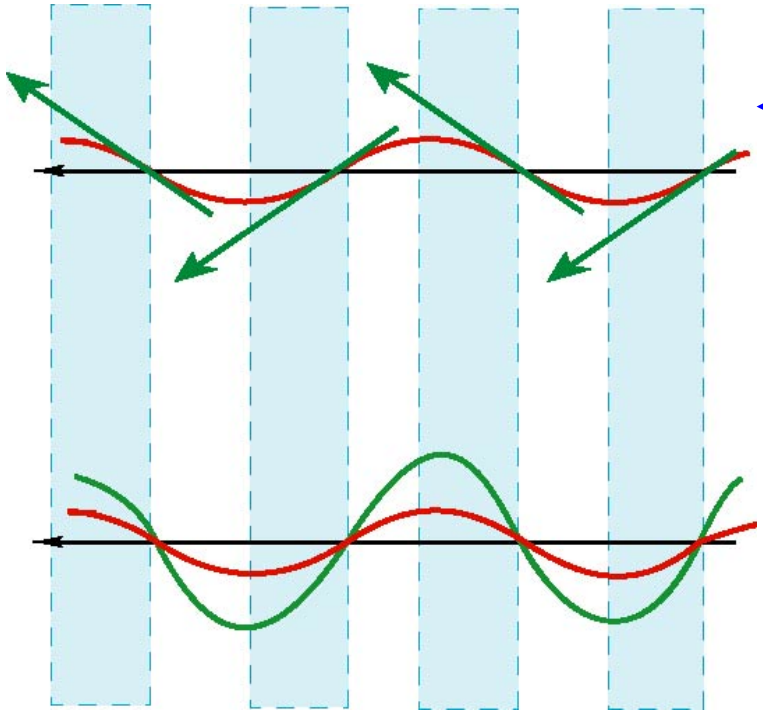
Carving and acceleration



Center of mass in motion



Cross-country versus Alpine



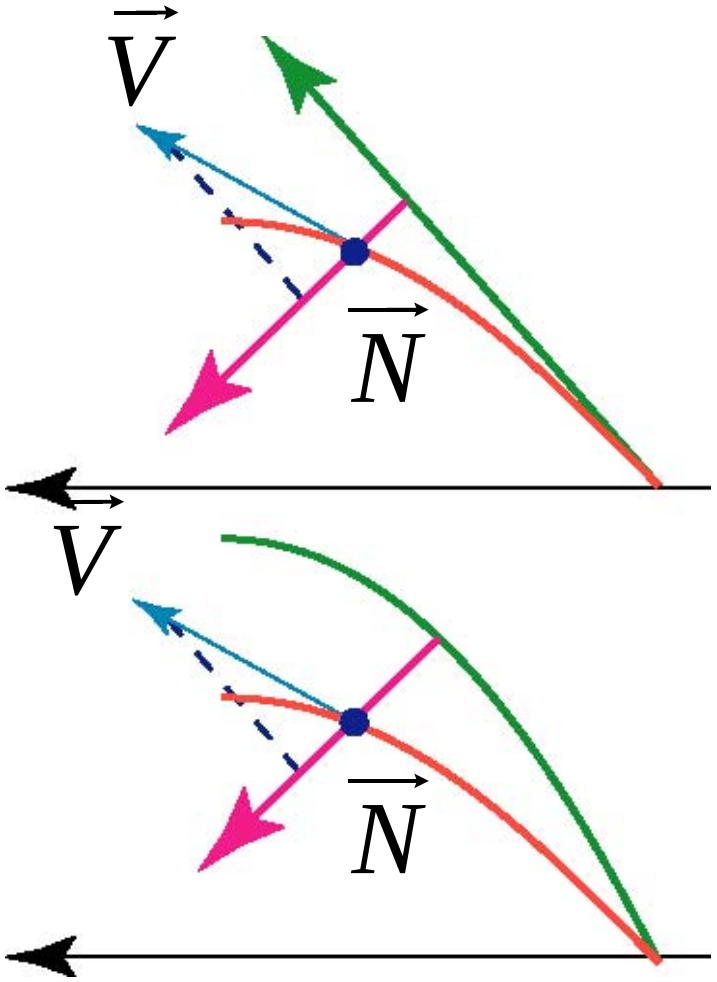
Cross country

center of mass

skis

Alpine

Acceleration



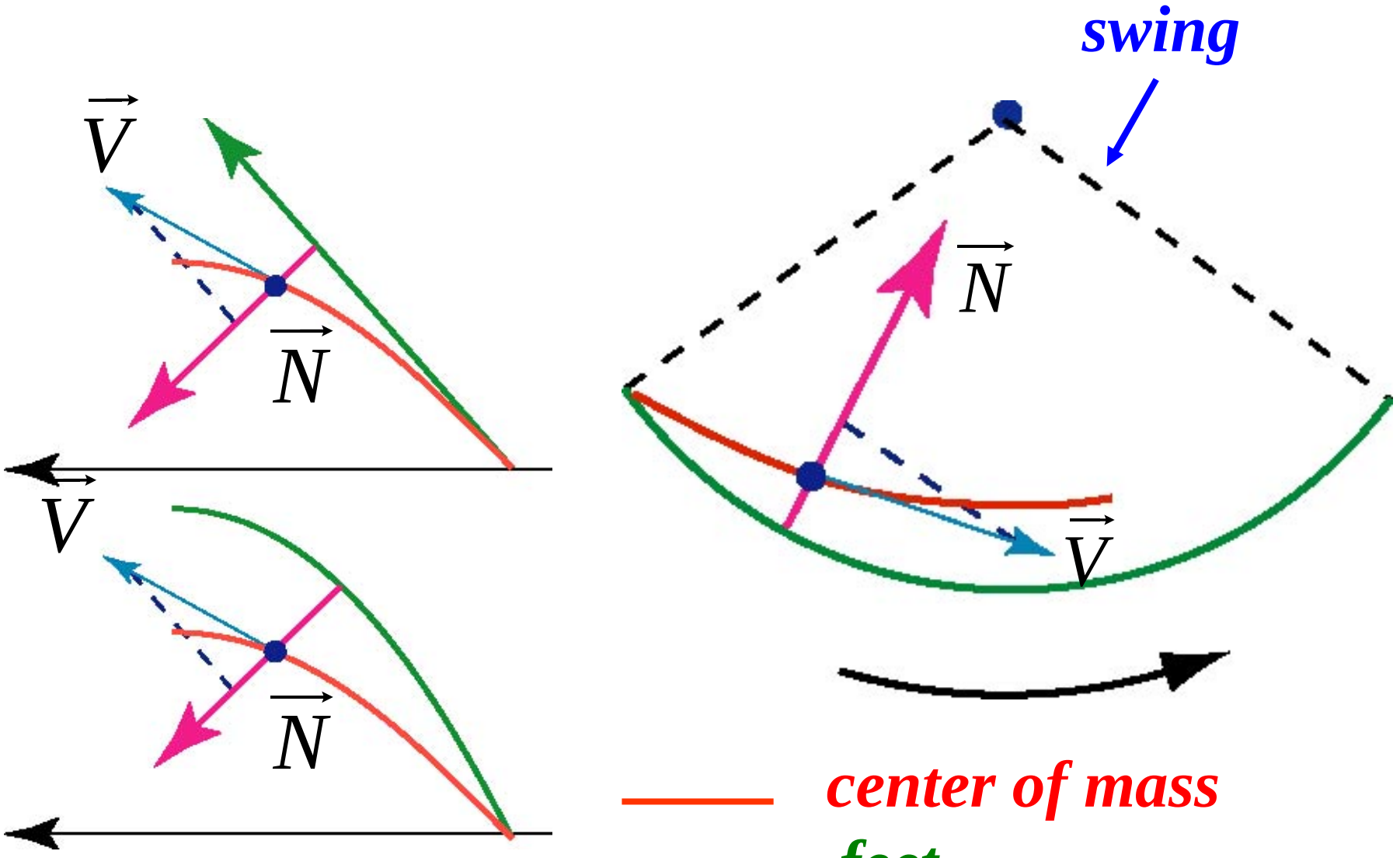
Cross country

center of mass

skis

Alpine

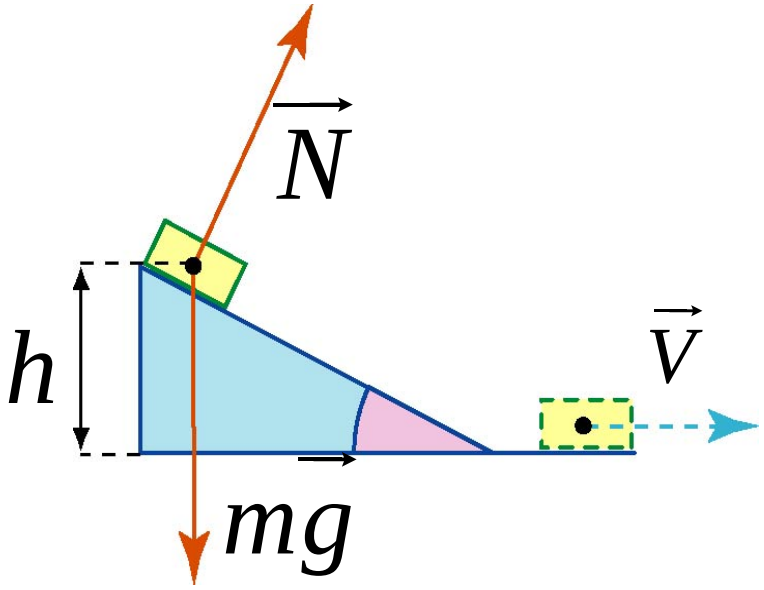
Acceleration



What it looks like

Ivica Kostelic, World Champion in slalom, 2003

Altitude loss and speed gain



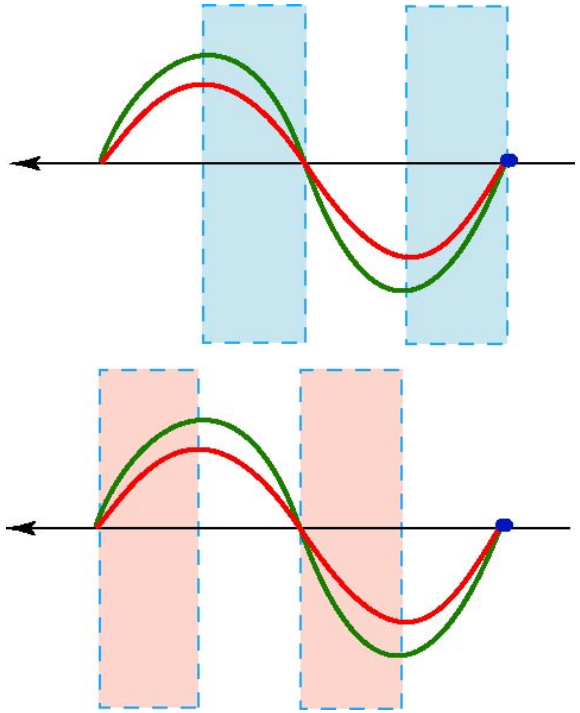
Energy conservation

$$\frac{mV^2}{2} = mgh;$$

$$V \sim 10\,m/s; \quad h \sim 5\,m!$$

Speed control

1. ***Passive*** *— skidding and carving;*
2. ***Active*** *— flexion–extension.*



Acceleration
(extension)

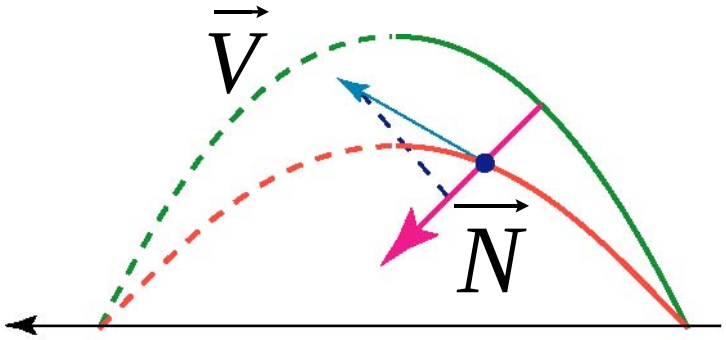
$$\vec{N} \cdot \vec{V} > 0;$$

Deceleration
(flexion)

$$\vec{N} \cdot \vec{V} < 0.$$

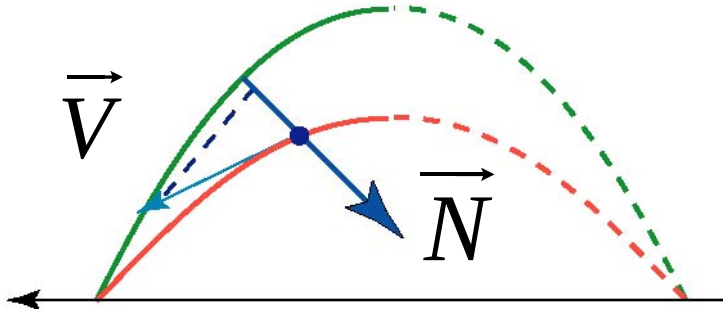
Speed control

1. ***Passive* — *skidding and carving;***
2. ***Active* — *flexion–extension.***



Acceleration
(extension)

$$\vec{N} \cdot \vec{V} > 0;$$



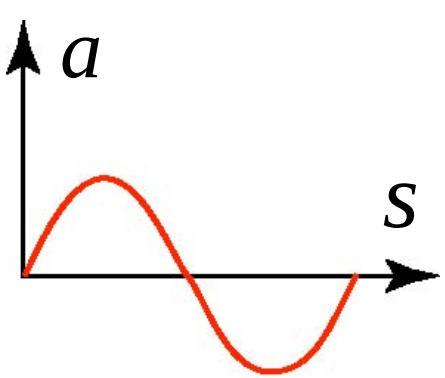
Deceleration
(flexion)

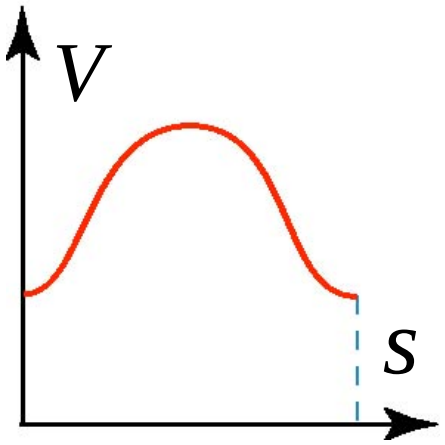
$$\vec{N} \cdot \vec{V} < 0.$$

Energy pumping

a — acceleration;
V — velocity;
s — distance;

Good (sportive) skier





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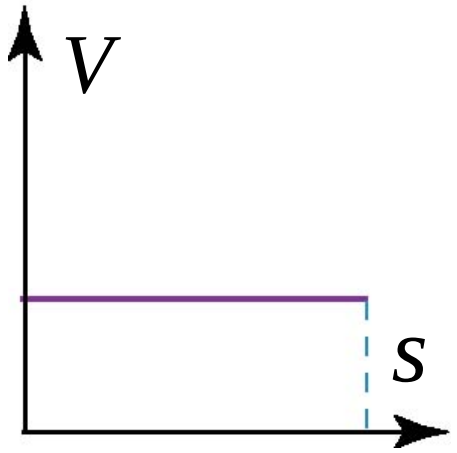
Bad (pastime) skier



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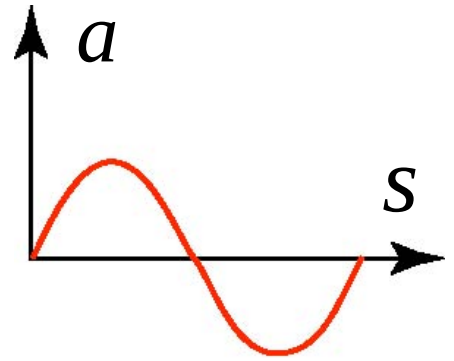
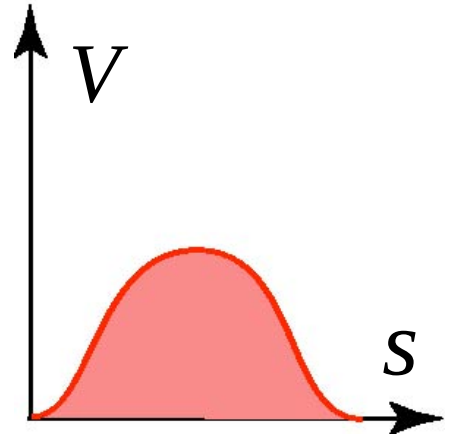




Physical factors in alpine skiing

1. *Gravity*
2. *Air drag (downhill, GS, SuperG)*
3. *Friction (skidding and carving)*
4. *Optimal trajectory (slalom)*
5. *Flexion-extension (slalom, GS)* ← **New!**

← **winners;**

loosers →

Gallery of Alpine Glory - I

Anton Sailer

Jean-Claude Killy

Gallery of Alpine Glory - II

Gustavo Thoeni

Ingemar Stenmark

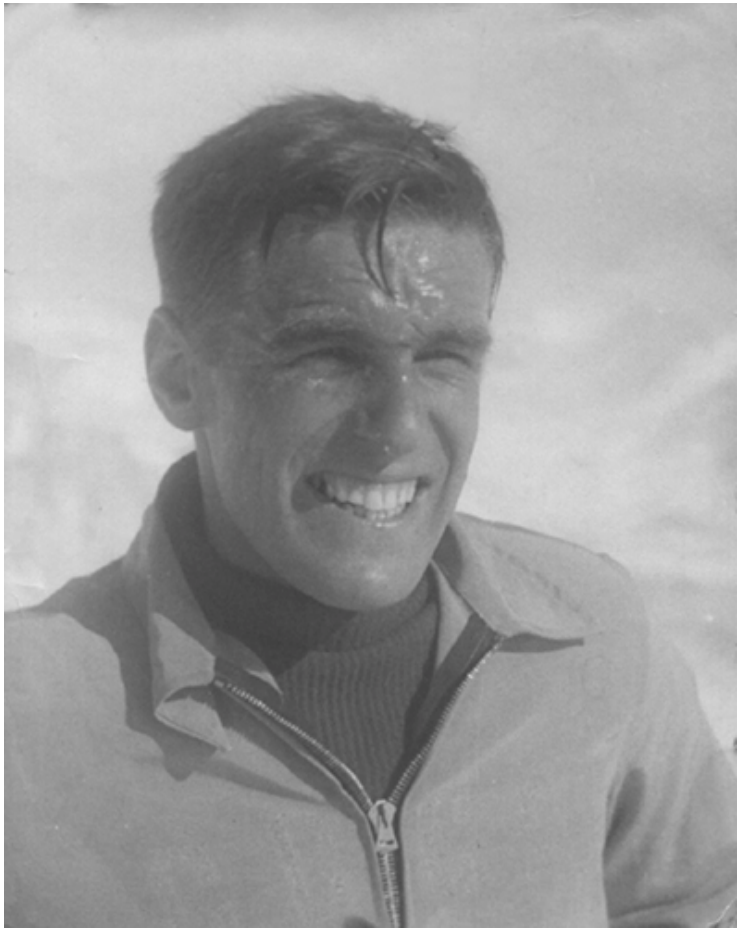
Gallery of Alpine Glory - III

Alexander Zhirov

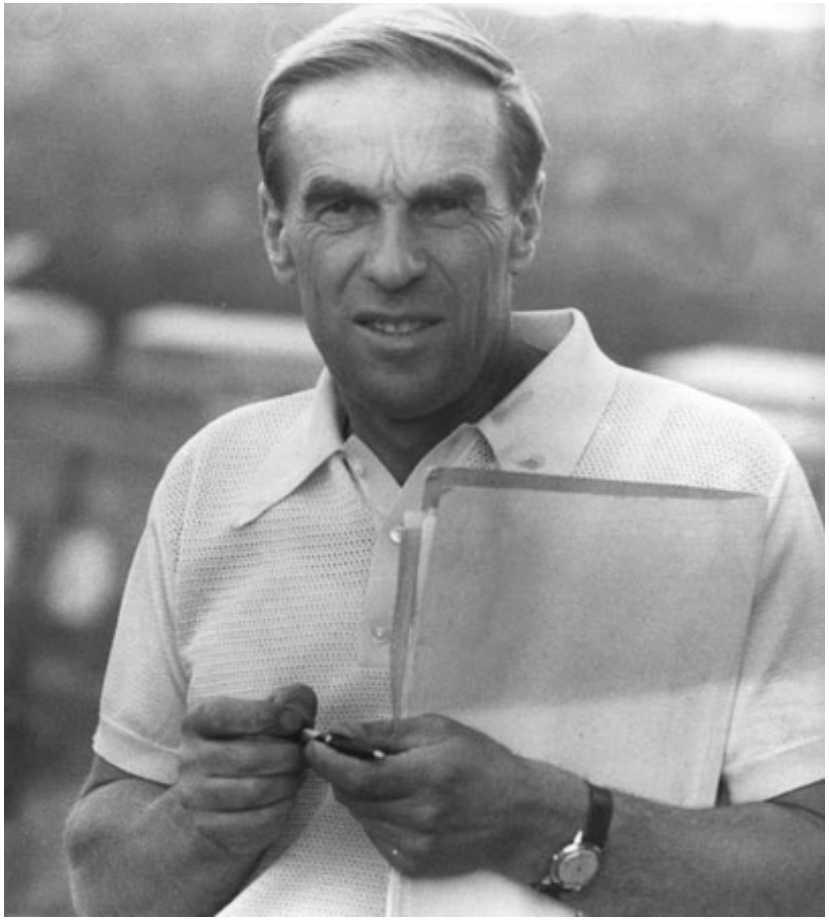
Alberto Tomba

Acknowledgements

Yuriy Preobrajenskiy



1948



1972

Alpine skiing is not the bliss

but

a perfect substitute