

Tutorial Lecture
ACSM Annual Conference
June 4, 2011

Mechanical Interactions of Snow-Skis-Skier



Mechanical Interactions of Snow-Skis-Skier



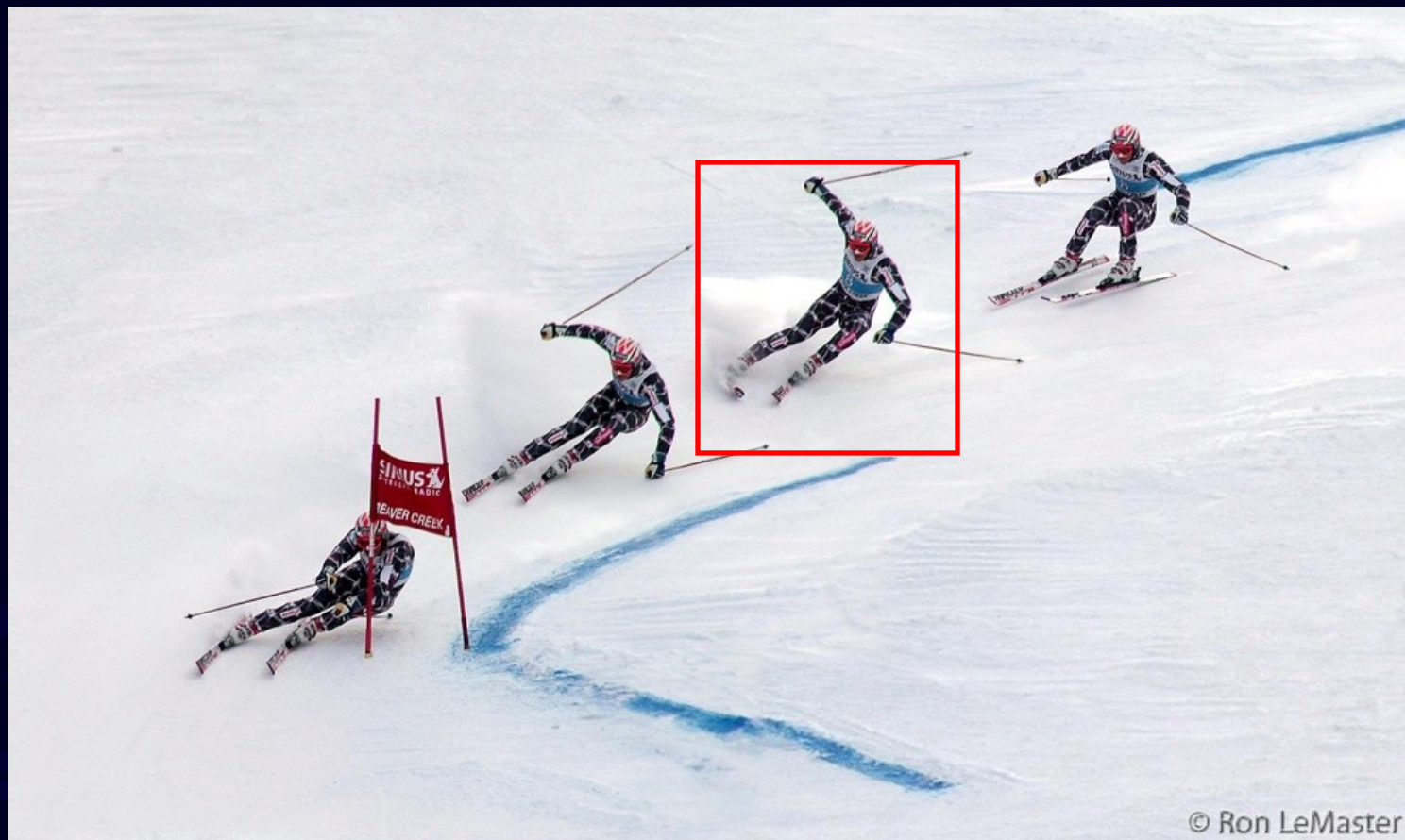
Christopher Brown

Worcester Polytechnic Institute
Worcester, MA



Robert C. Reid

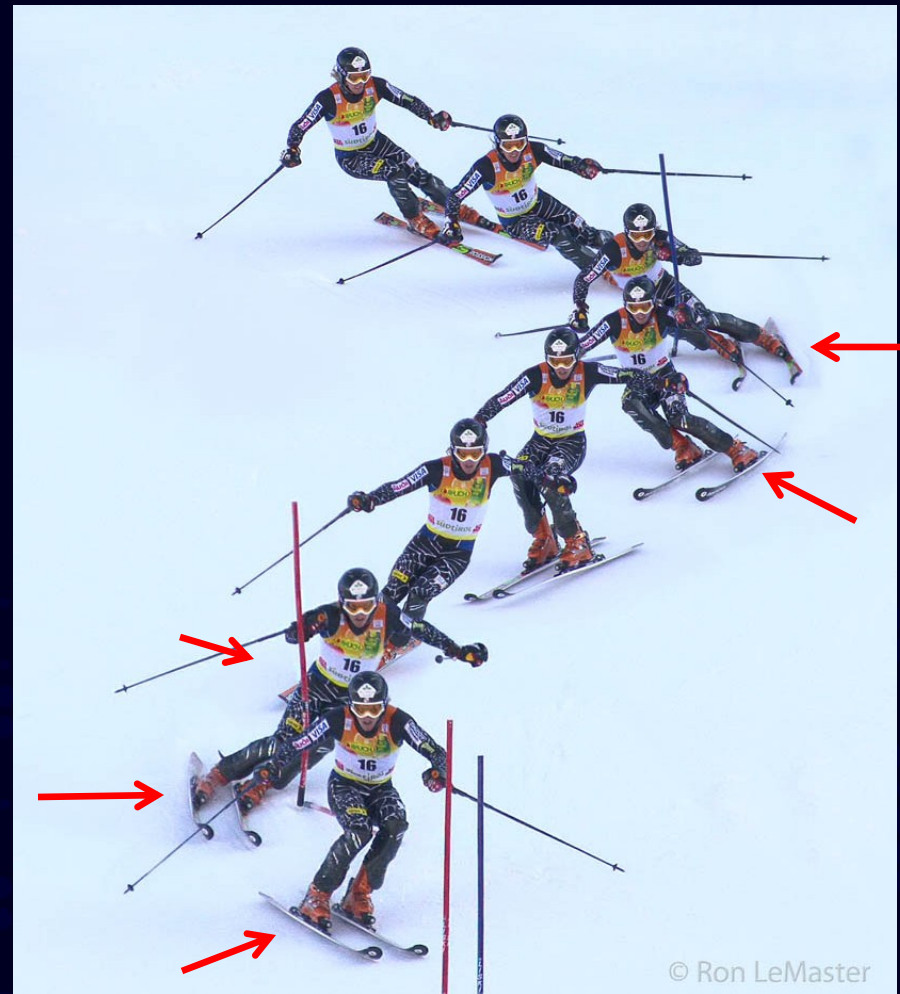
Norwegian School of Sport Science
Oslo, Norway



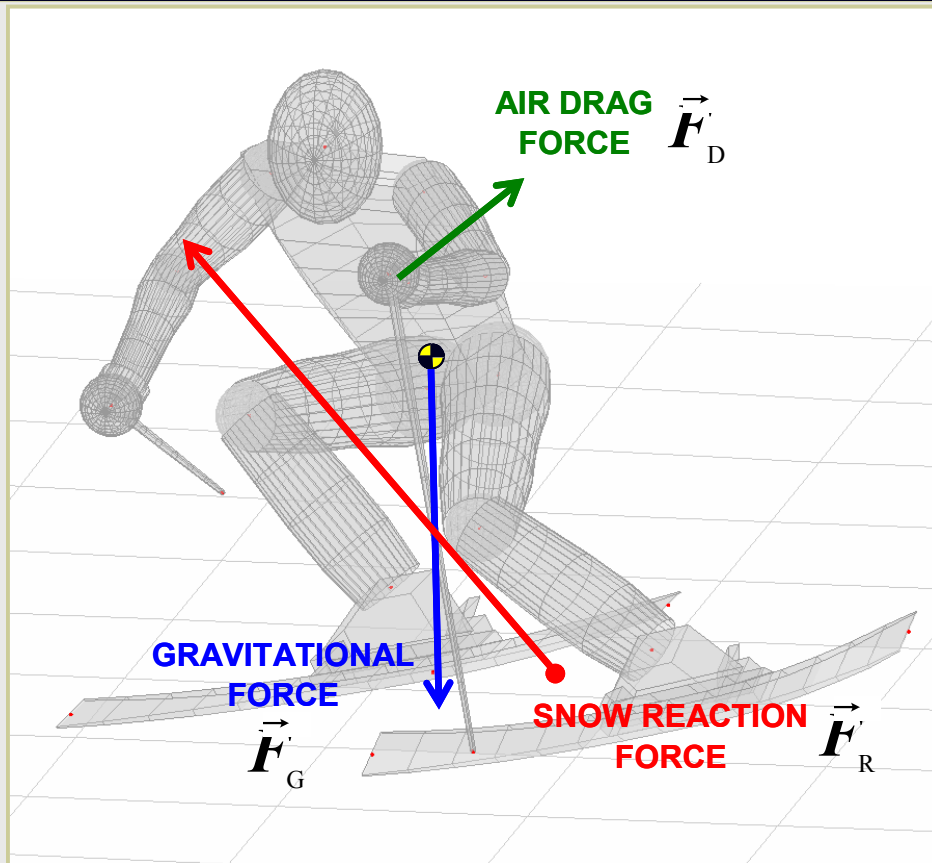
Aksel Lund Svindal, Beaver Creek 2006

“Years ago I read an article about a successful race car driver that changed the way I thought about skiing. The driver said that everything he did behind the wheel was motivated and judged by the effect on the four patches of contact his tires made with the pavement. Since then, I have come to think that every element of ski technique should be evaluated in terms of how it affects our interaction with the snow.”

(LeMaster, 1999, p. 3)



Ted Ligety, Alta Badia, 2007



Equation of Motion

$$m\vec{a}_{\text{COM}} = \vec{F}_R + \vec{F}_D + \vec{F}_G$$

(Lüthi et al., 2005)

**LATERAL
ACTIONS**

**VERTICAL
ACTIONS**

**SKI SNOW
INTERACTION**

**ROTARY
ACTIONS**

**FORE/AFT
ACTIONS**

Lateral Actions

Those actions occurring primarily in the skier's frontal plane and whose goals include:

- Incline the center of mass into the turn.
- Regulate the ski edge angle (Angulation).
- Align body segments.

(Howe, 2001; Joubert, 1978; LeMaster, 1999, 2010; Lind & Sanders, 2004; Witherell, 1972)



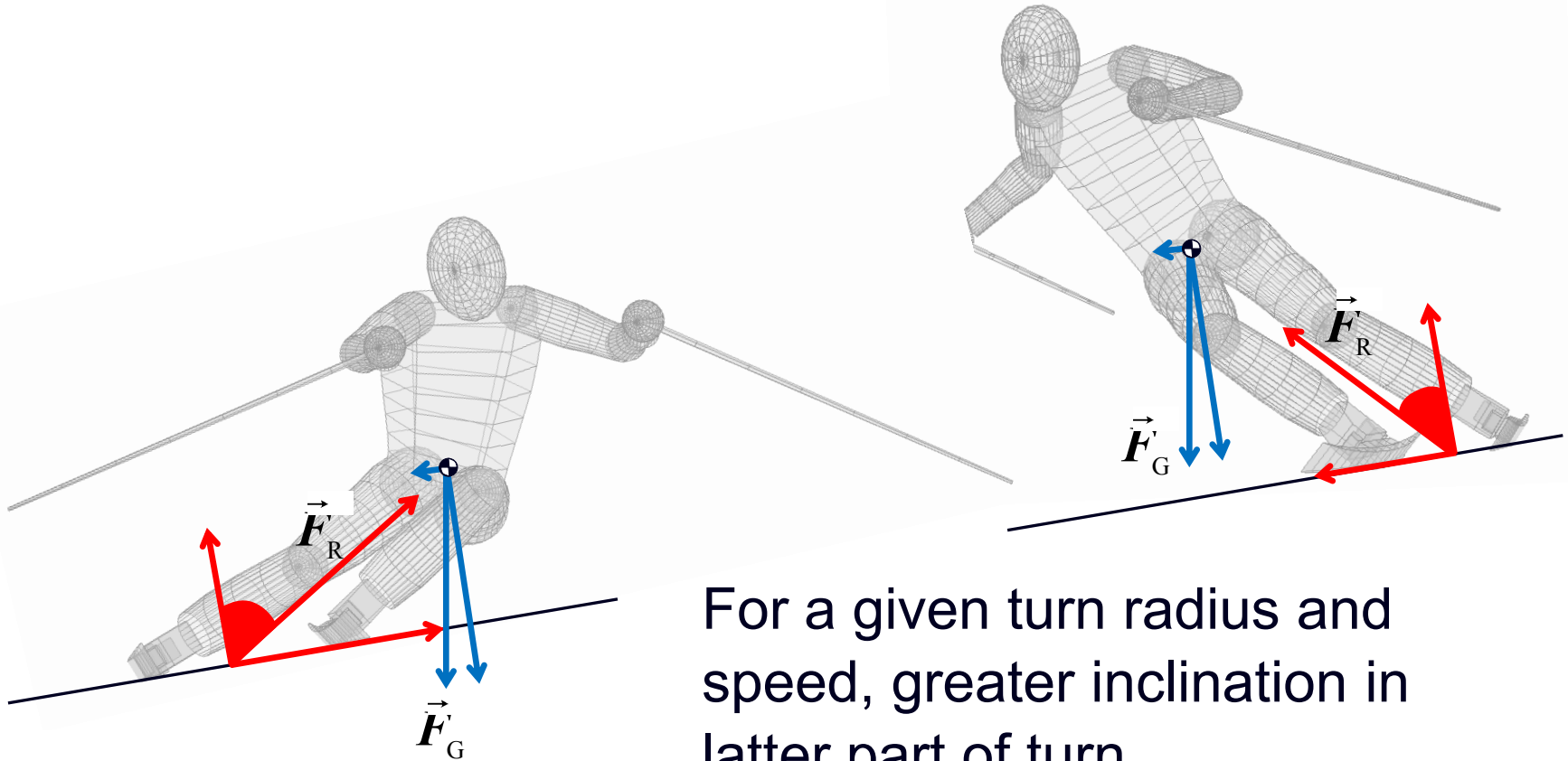
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

COM Inclination



For a given turn radius and speed, greater inclination in latter part of turn.

LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

COM Inclination

We do not always ski
in equilibrium with the
external forces.



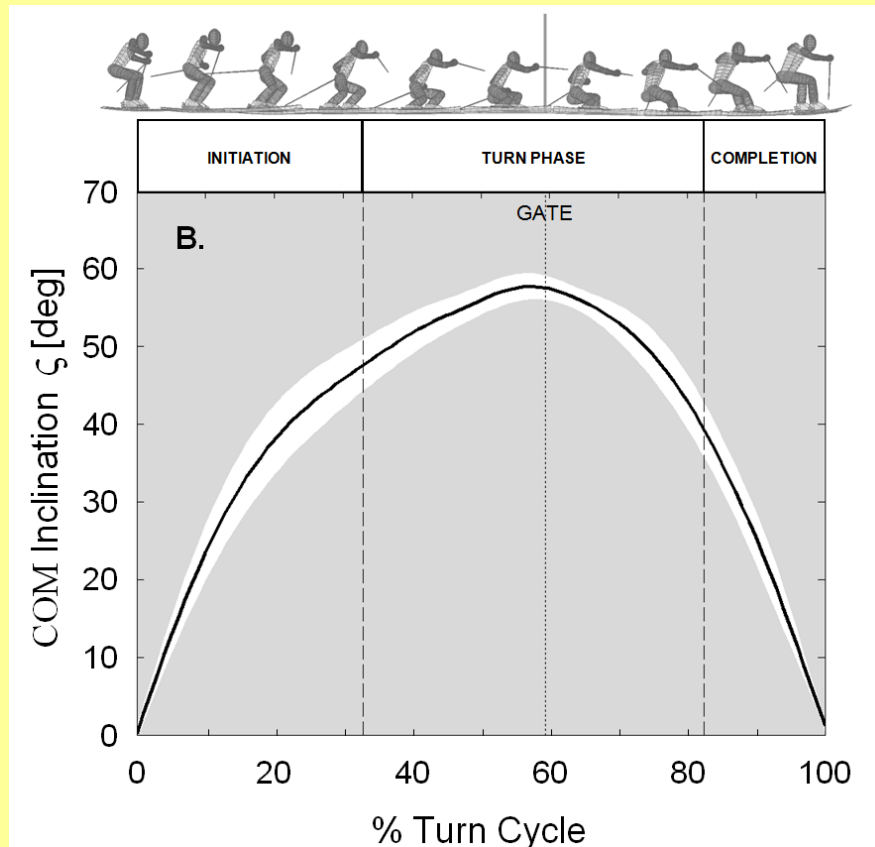
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

COM Inclination



(Reid, 2010)

COM inclines rapidly during turn initiation, reaching maximum values at gate passage.

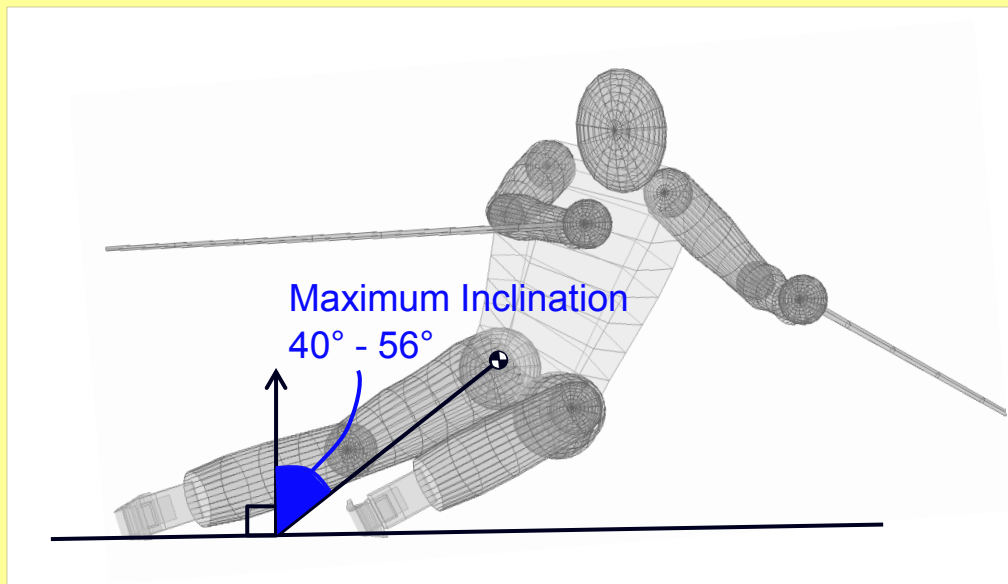
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

COM Inclination



(Miura & Miura, 2004; Raschner, 1997; Reid, 2010)

Divergence of Ski and COM Trajectories

Morawski (1973):

- COM Inclination is the main factor controlling the intensity of the turn.
- Skis and skier required to follow separate trajectories to achieve inclination.

"Divergence"

(Joubert, 1978; LeMaster, 1999; Major & Larsson, 1979;
Witherell, 1972)

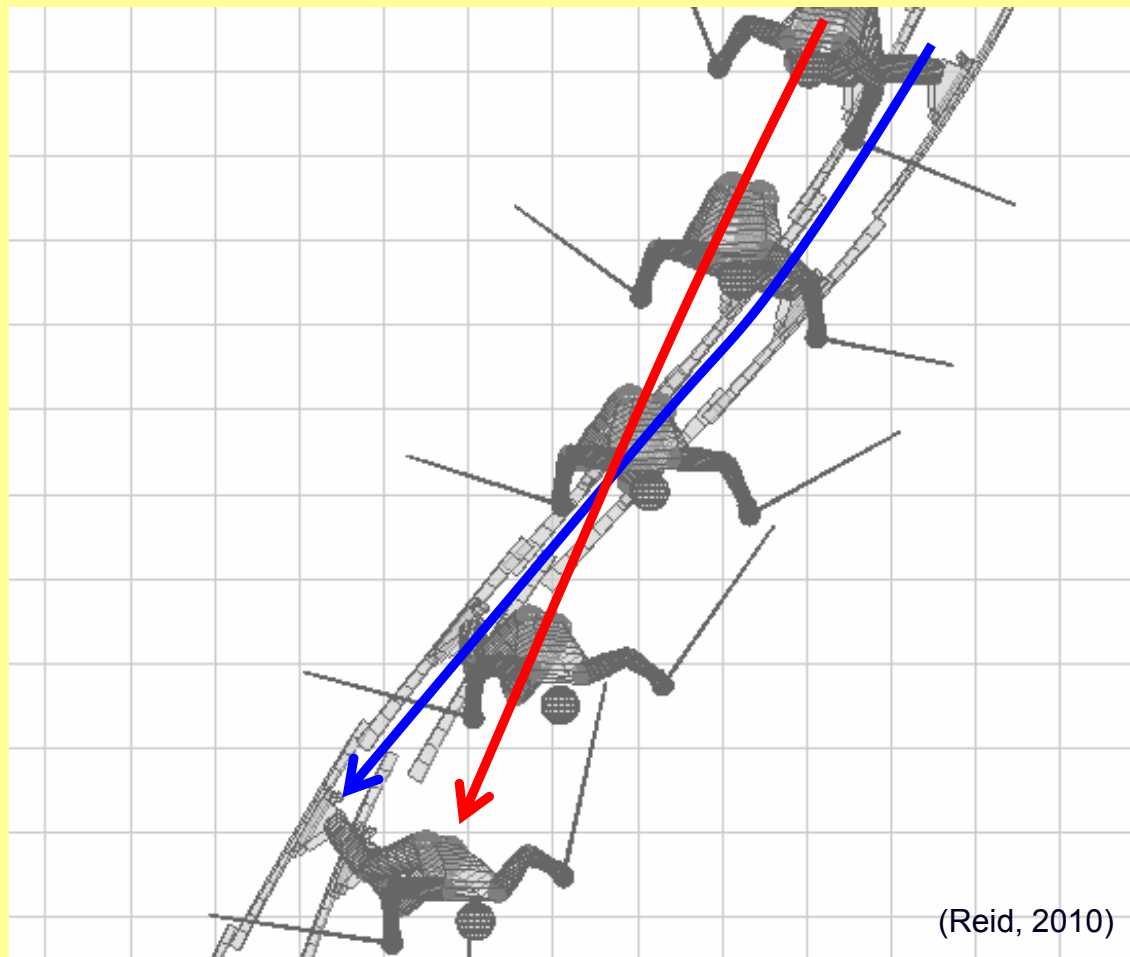
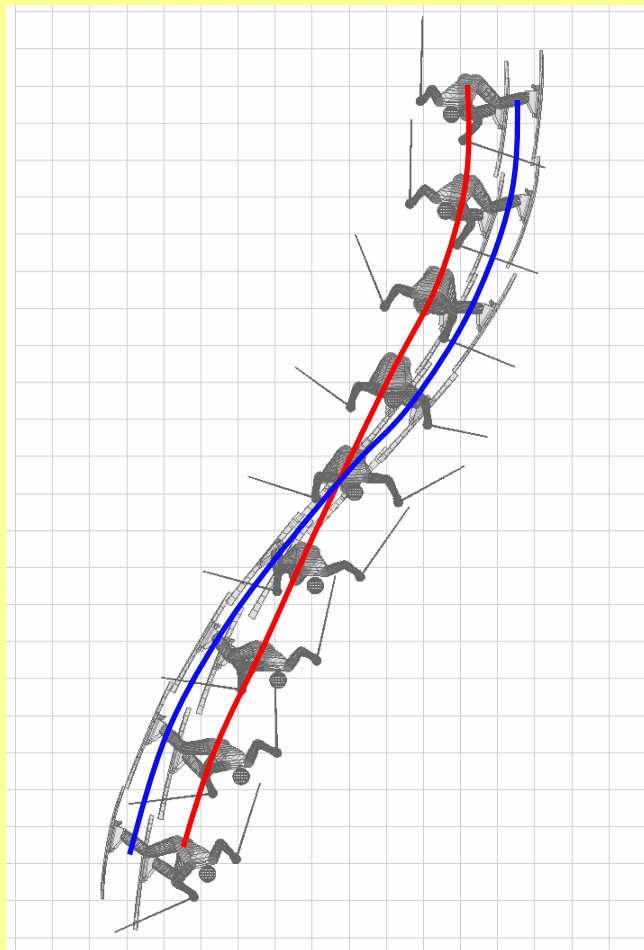
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Divergence of Ski and COM Trajectories



(Reid, 2010)

LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Hip Angulation

Angling in the body "that brings the head of the femur closer to the center of the turn without moving the COM laterally."

(LeMaster, 1999)



LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Knee Angulation



Angling in the lower limb
"brings the knee closer to
the body mid-line without
disturbing the COM
laterally."

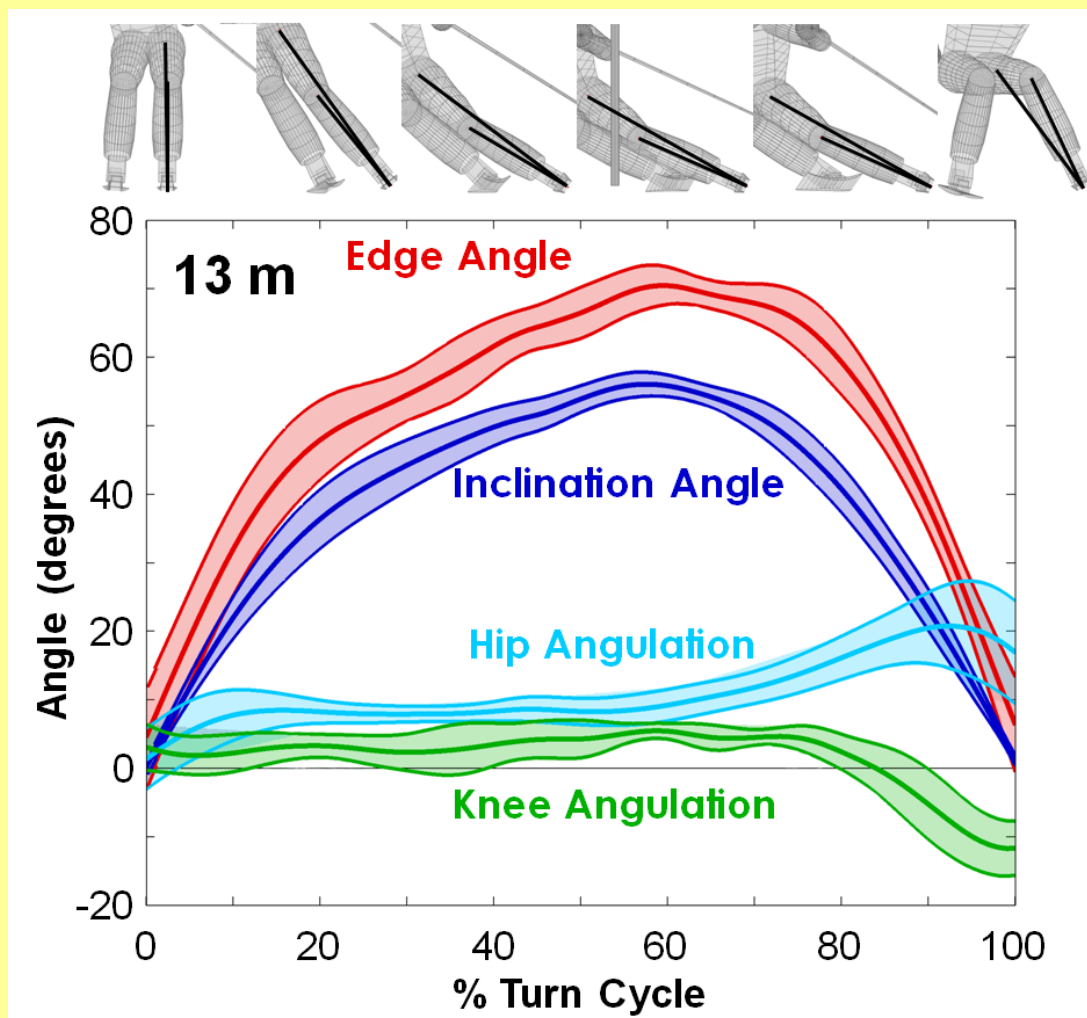
(LeMaster, 1999)

LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS



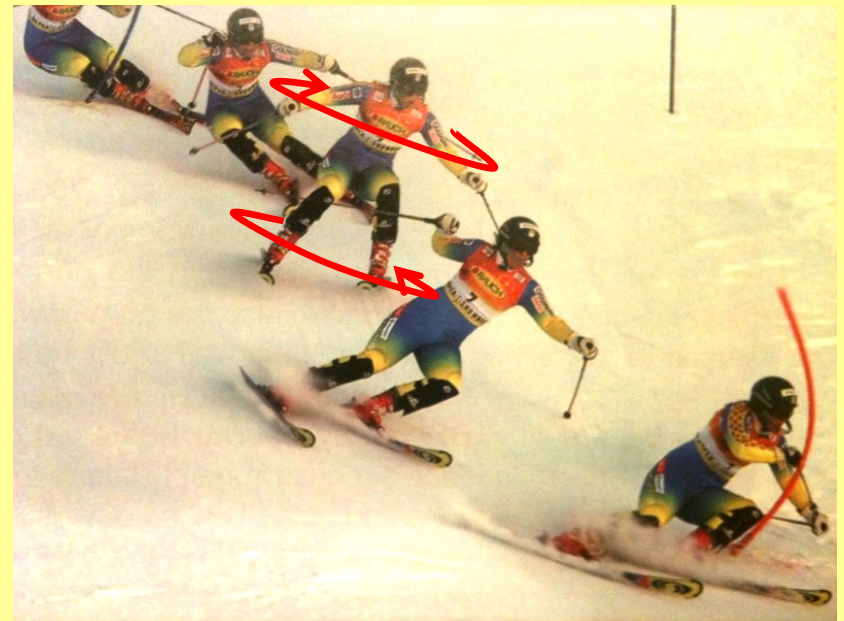
(Kipp et al., 2010)

Rotary Actions

Those actions directed towards controlling the rotary motion of the skis and occurring predominantly in the skier's horizontal plane:

- Rotate skis onto a trajectory from which they can carve.
- Regulate speed.
- Regulate the ski's turning behaviour.

(Joubert, 1978; LeMaster, 1999; Major & Larsson, 1979; Witherell, 1972; Witherell & Evrard, 1993)



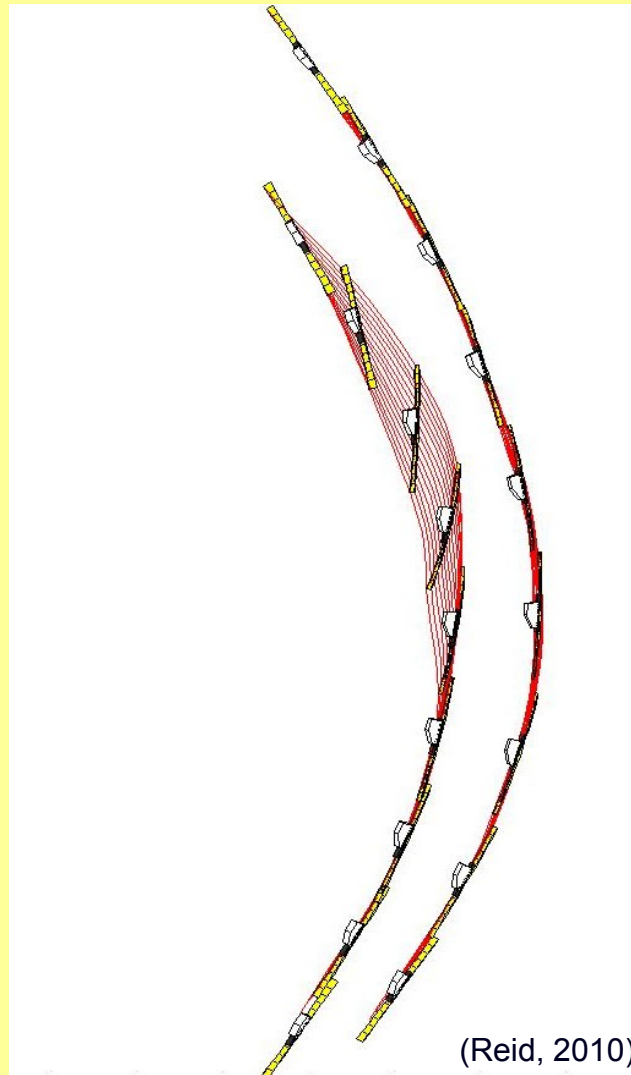
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Rotate Skis onto a Carving Trajectory



(Reid, 2010)

LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Speed Regulation



© Ron LeMaster

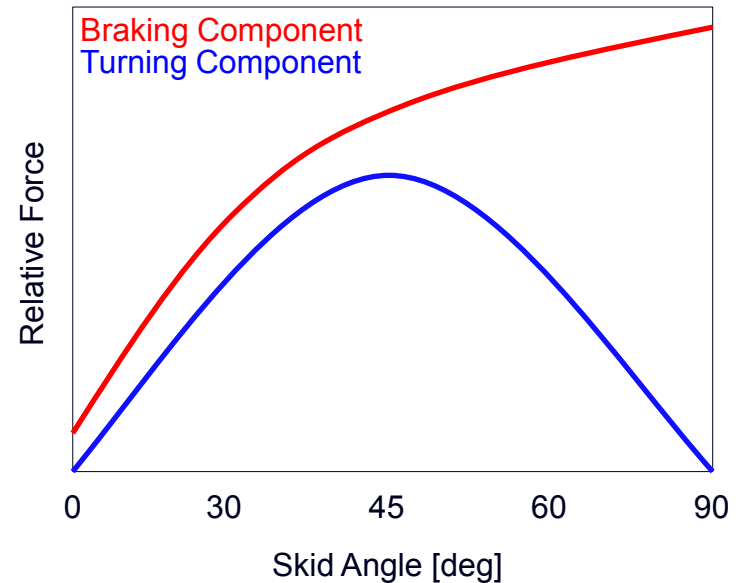
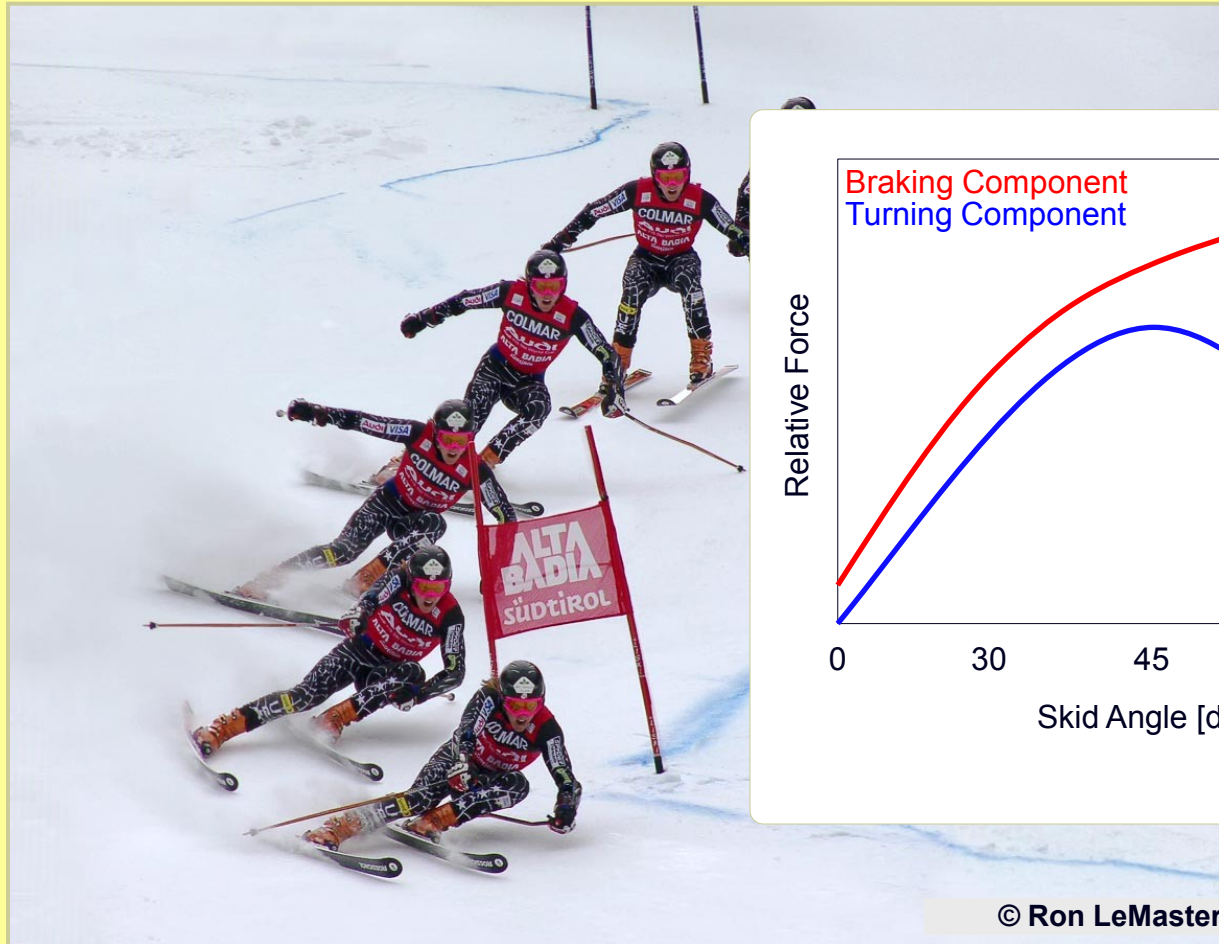
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Speed Regulation



(LeMaster, 1999)

© Ron LeMaster

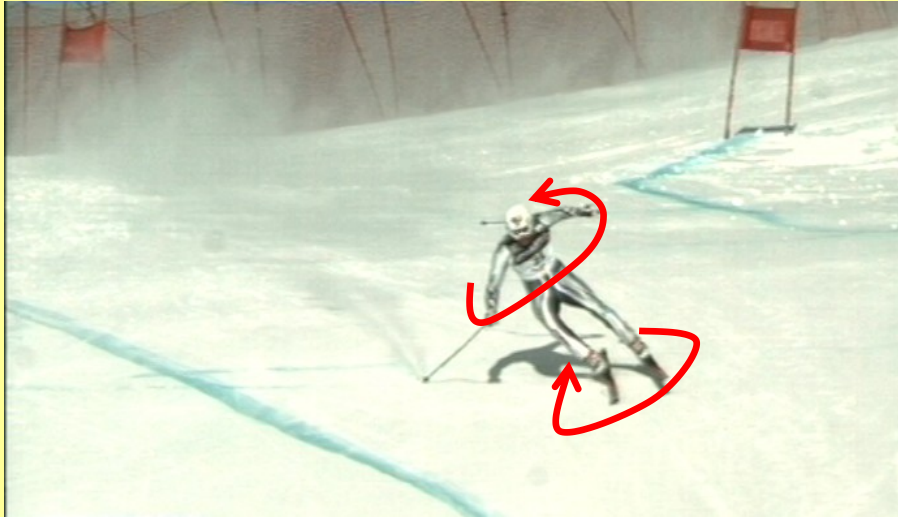
Counter-Rotation



- Skis disengaged from the snow.
- Rotate upper body in one direction causing skis to rotate in the opposite direction.
- Actions that stabilize the upper body allow a greater moment to be transferred to the lower body.

(Bear, 1976; Joubert, 1978; LeMaster, 1999;
Major & Larsson, 1979)

Counter-Rotation



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- Rotate upper body in one direction causing skis to rotate in the opposite direction.
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(Bear, 1976; Joubert, 1978; LeMaster, 1999;
Major & Larsson, 1979)

Wind up and Release

- Upper body is twisted to face downhill as the skis turn underneath the body.
- Resulting torsion stores energy in the stretched muscles, ligaments and tendons of the torso.
- Upper body blocked and skis released, allowing stretched muscles to rotate skis back into alignment.



(Major & Larsson, 1979)

(Joubert, 1978; LeMaster, 1999, Major & Larsson, 1979)

Thigh Rotation

- Rotation about the hip joint.
- Can be used without having to generate rotation in other body parts.
- Fine tuning.
- When inclined, regulates how aggressively shovel interacts with the snow.

(Joubert, 1978; Witherell, 1972;
Witherell & Evrard, 1993)



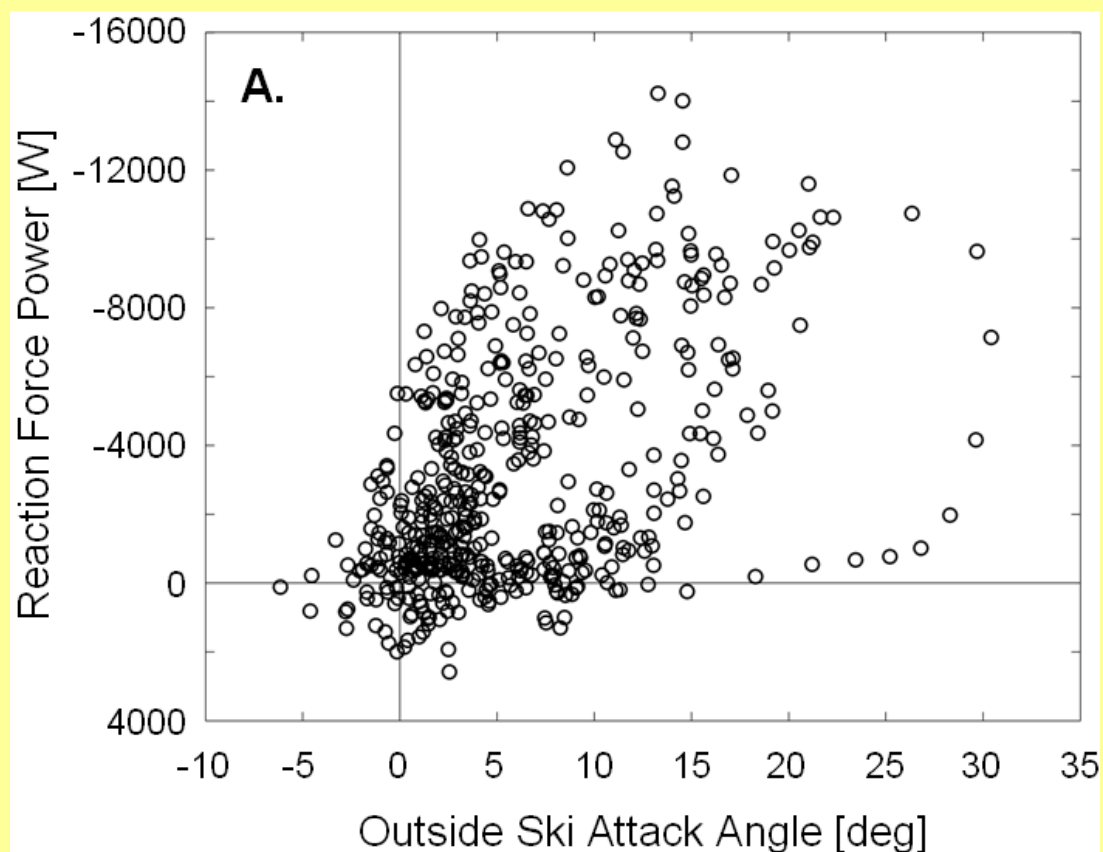
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Skidding & Energy Dissipation



(Reid, 2010)

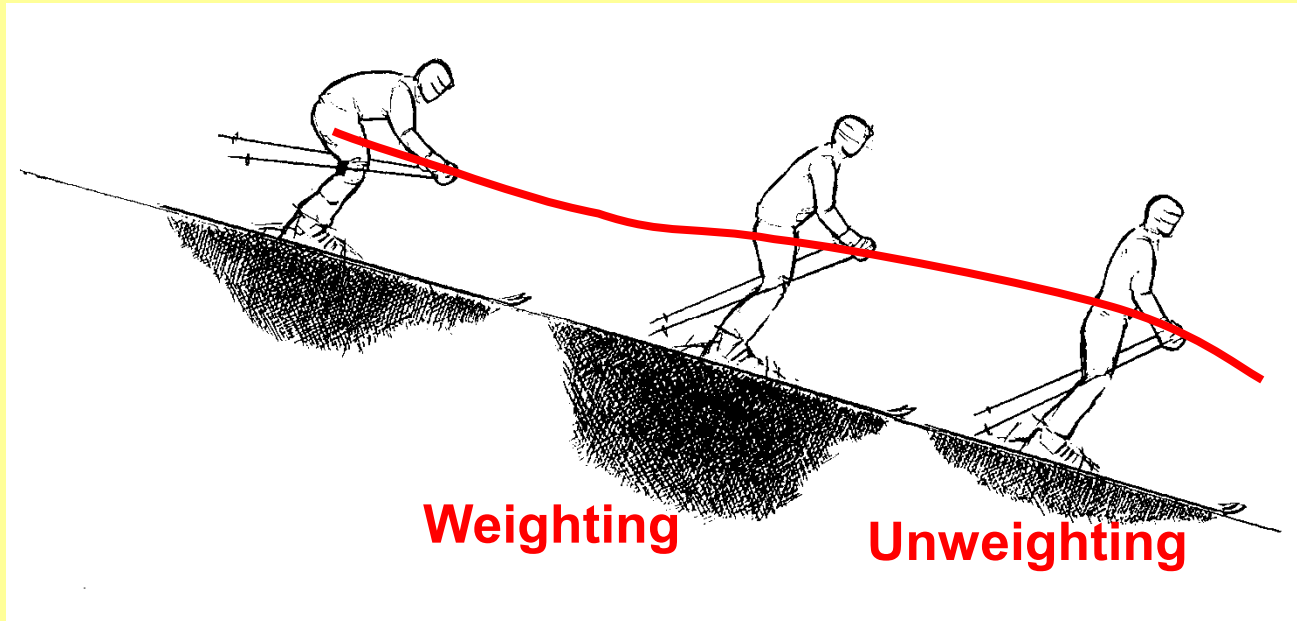
Vertical Actions

Those actions that take place largely in the skier's sagittal plane and whose goals include:

- Regulate the magnitude of the snow reaction force.
- Align body segments.
- Increase speed.



Up-Unweighting



(Müller, 1994)

An initial loading and acceleration away from the snow surface is followed by an acceleration towards the snow and unweighting.

(Bear, 1976; Joubert, 1978; LeMaster, 1999; Major & Larsson, 1979)

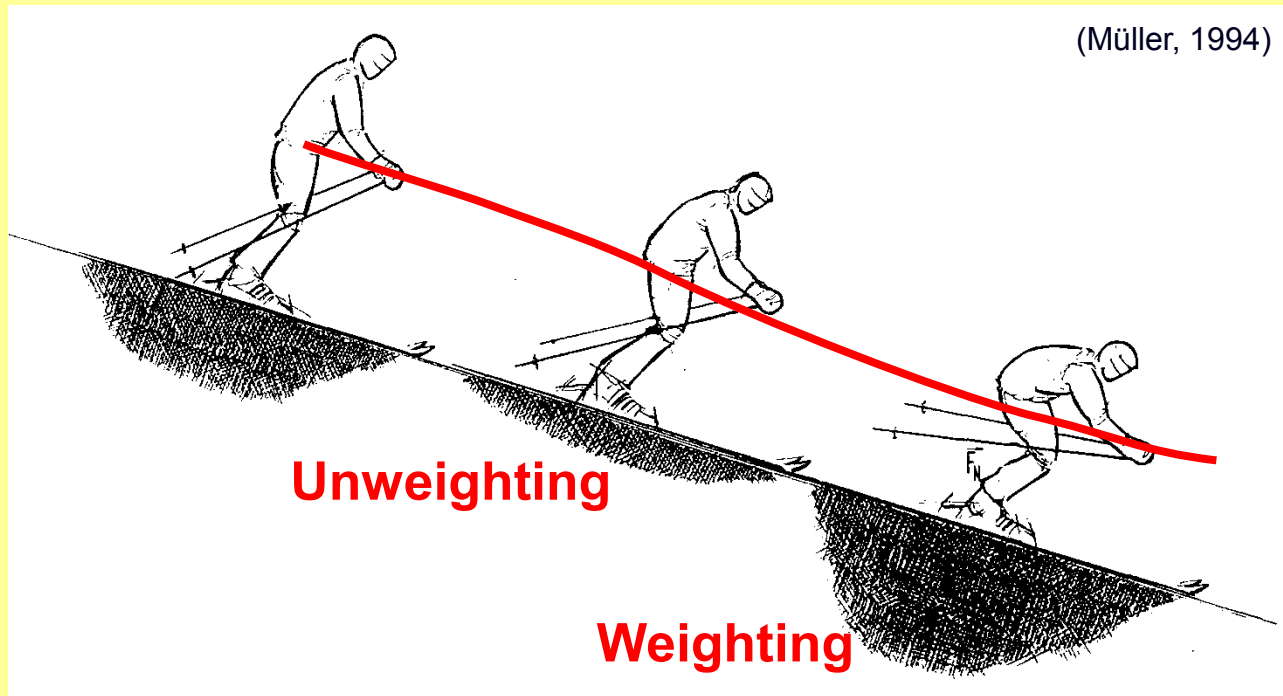
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Down-Unweighting



A reduction in snow reaction force through an immediate acceleration of the COM towards the snow surface.

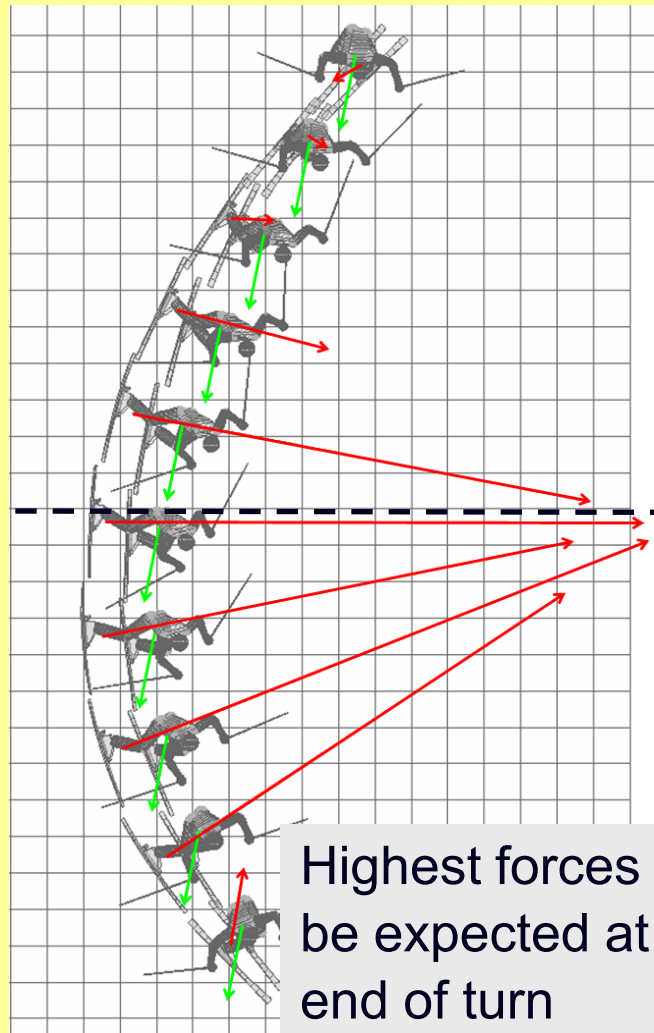
(Bear, 1976; Joubert, 1978; LeMaster, 1999; Major & Larsson, 1979)

LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS



**Gravity
assists
turning**

**Gravity
resists
turning**

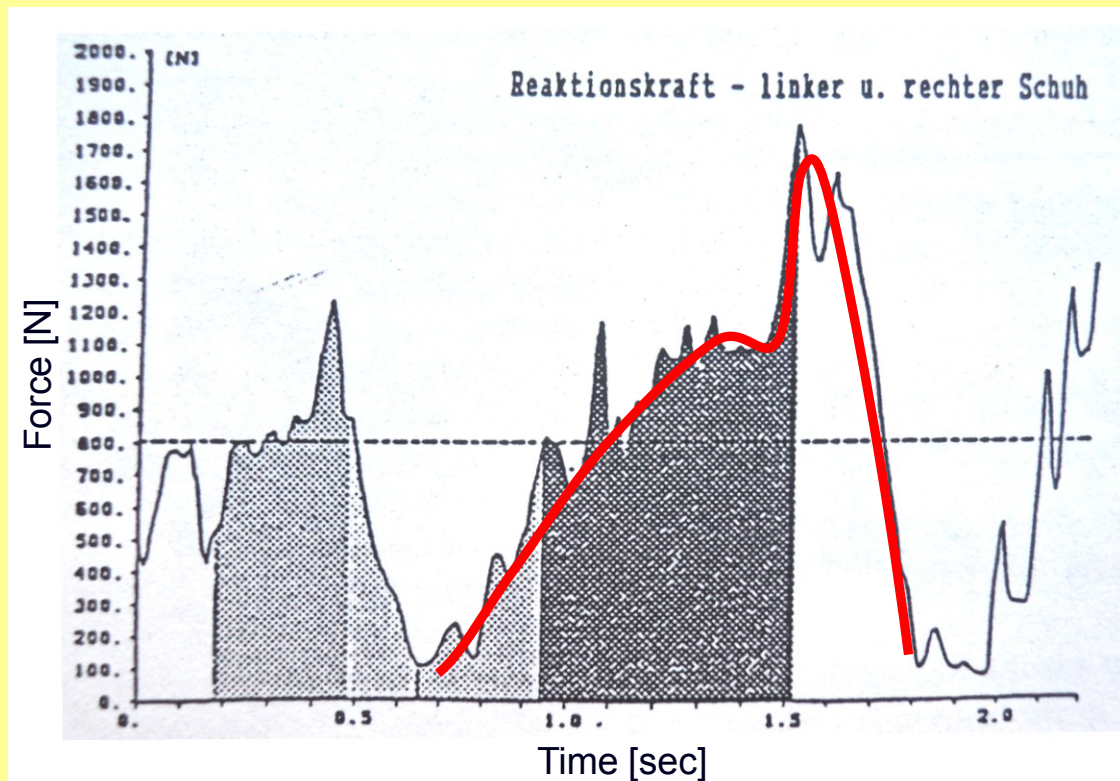
Highest forces to
be expected at
end of turn

LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS



(Nachbauer, 1987)

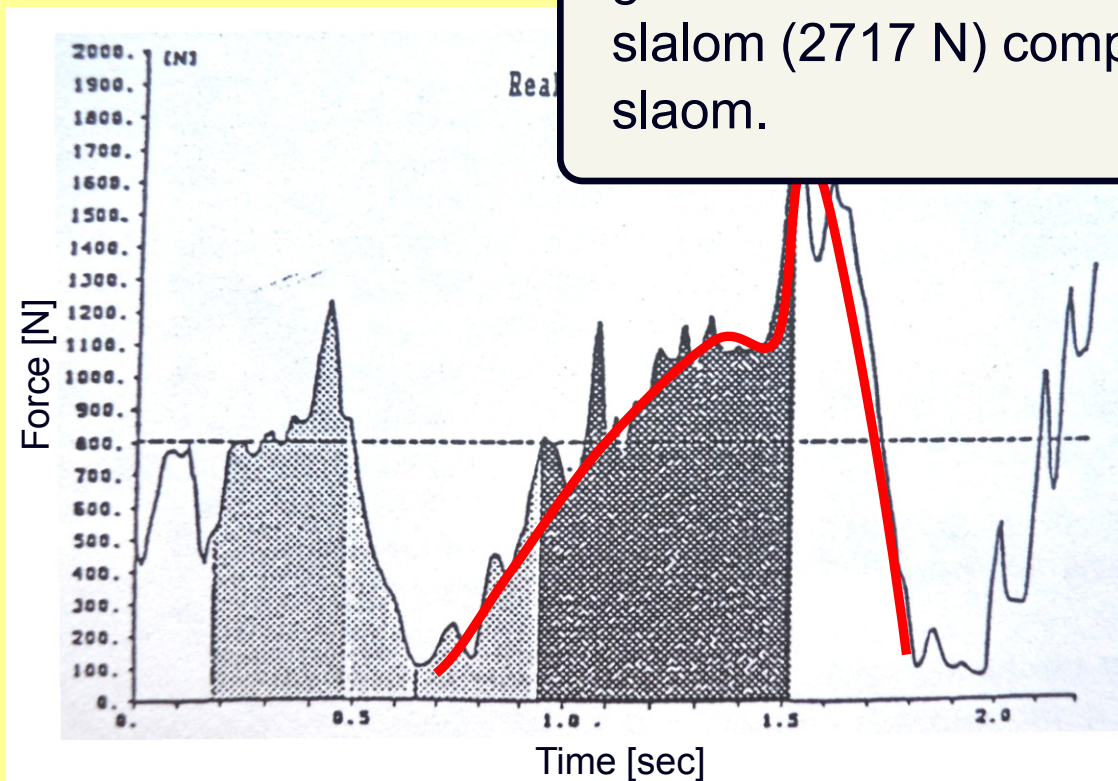
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Nachbauer (1987): Maximum ground reaction forces larger in slalom (2717 N) compared to giant slalom.



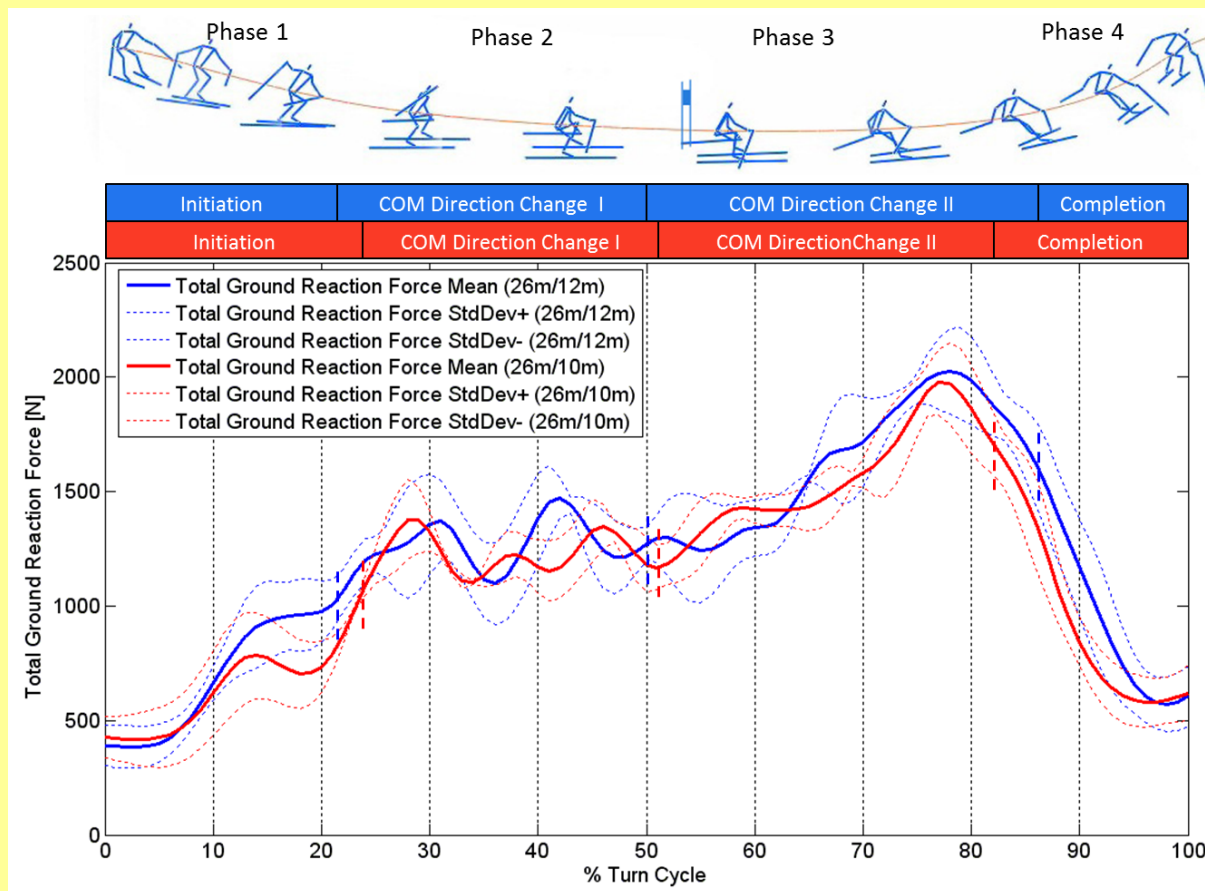
(Nachbauer, 1987)

LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS



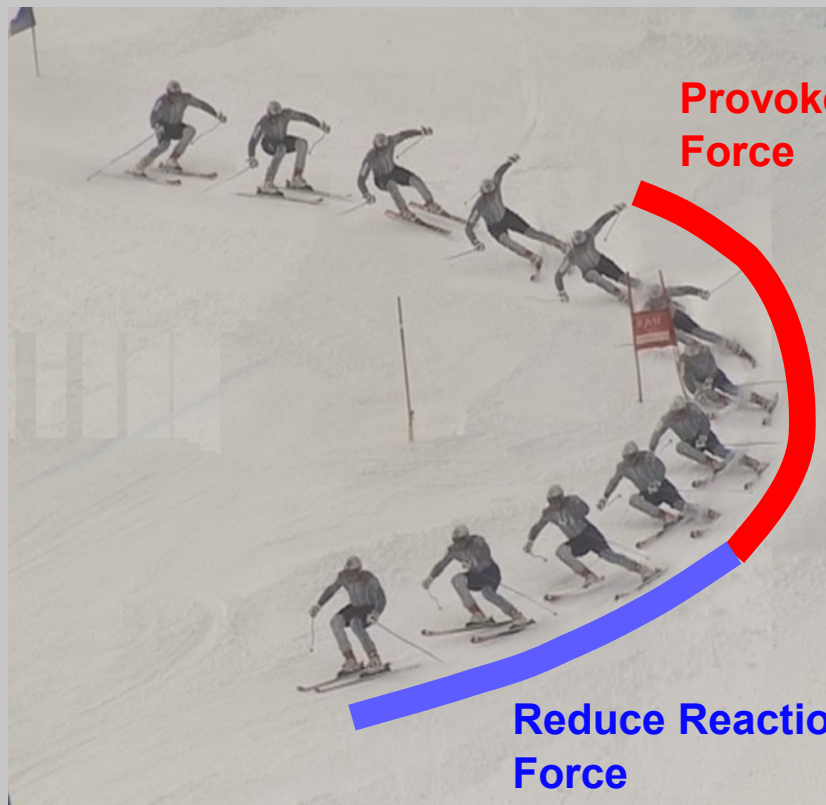
(Spörri, 2010)

LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS



Provoke Reaction
Force

Reduce Reaction
Force

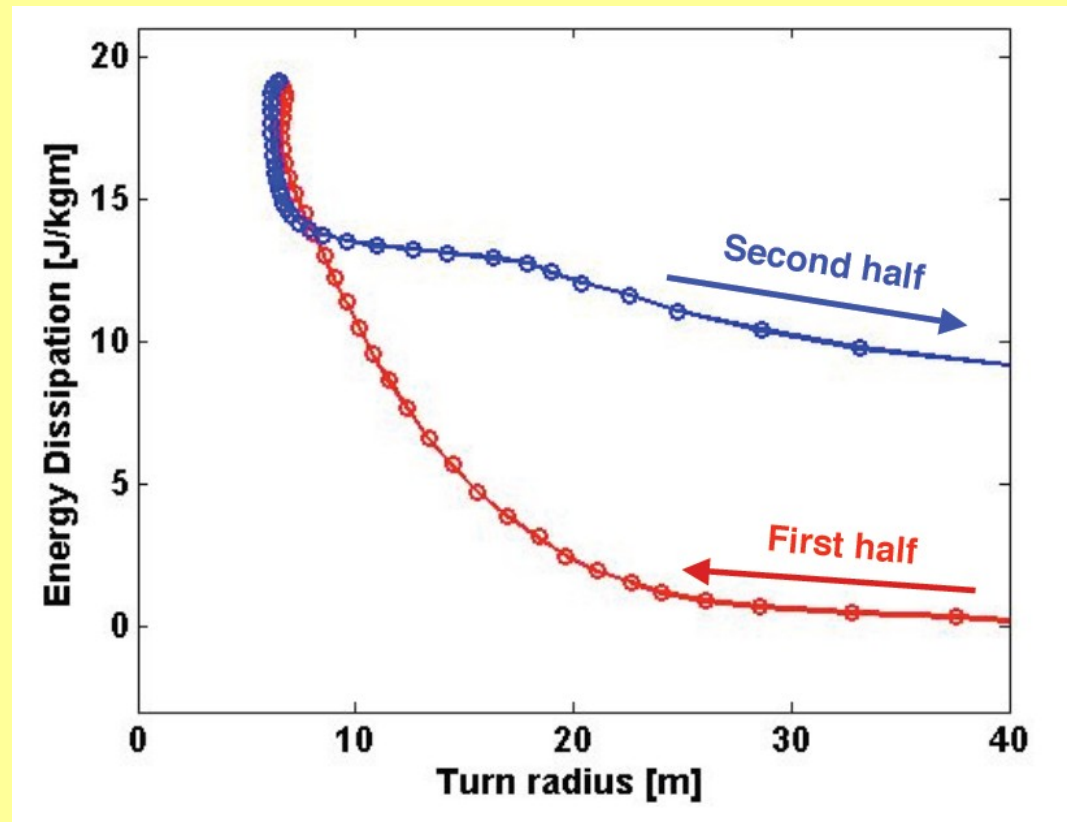
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Increased energy dissipation for a given COM turn radius in later portion of the turn.



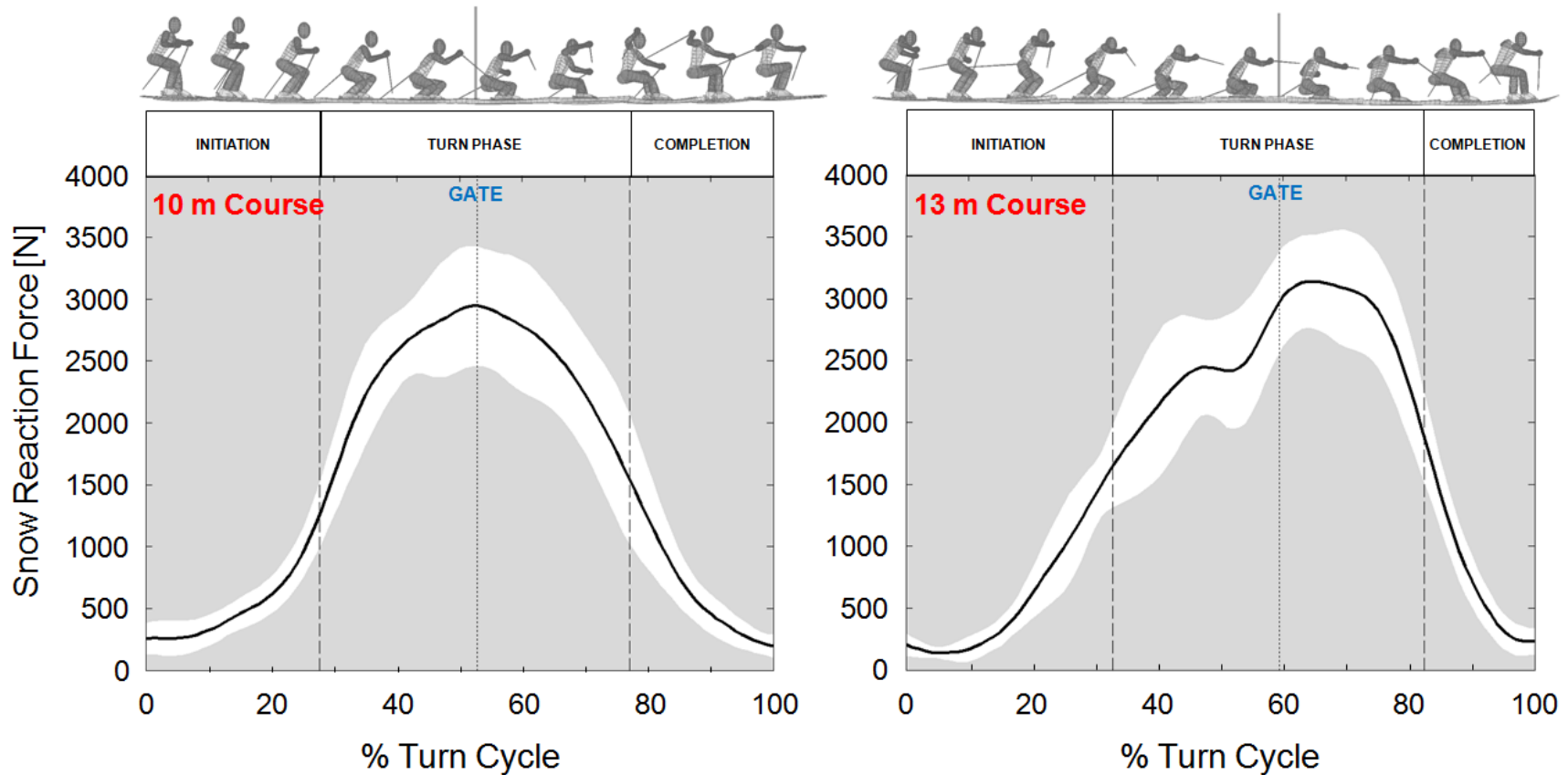
(Gilgien, 2007)

LATERAL ACTIONS

ROTARY ACTIONS

VERTICAL ACTIONS

FORE/AFT ACTIONS



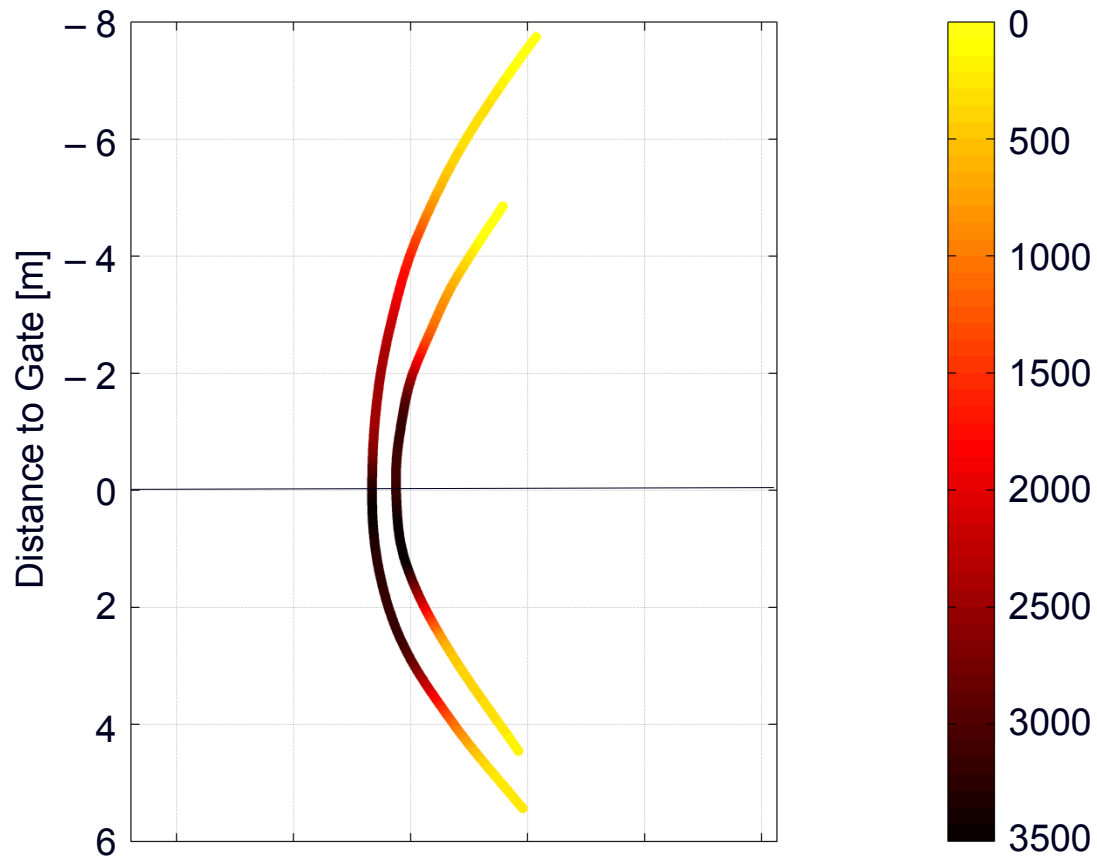
(Reid, 2010)

LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS



(Reid, 2010)

LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Pumping to Increase Speed

Journal of Sound and Vibration (1983) **88**(1), 107–115

ACCELERATIONS INDUCED BY BODY MOTIONS DURING SNOW SKIING

C. D. MOTE, JR AND J. K. LOUIE

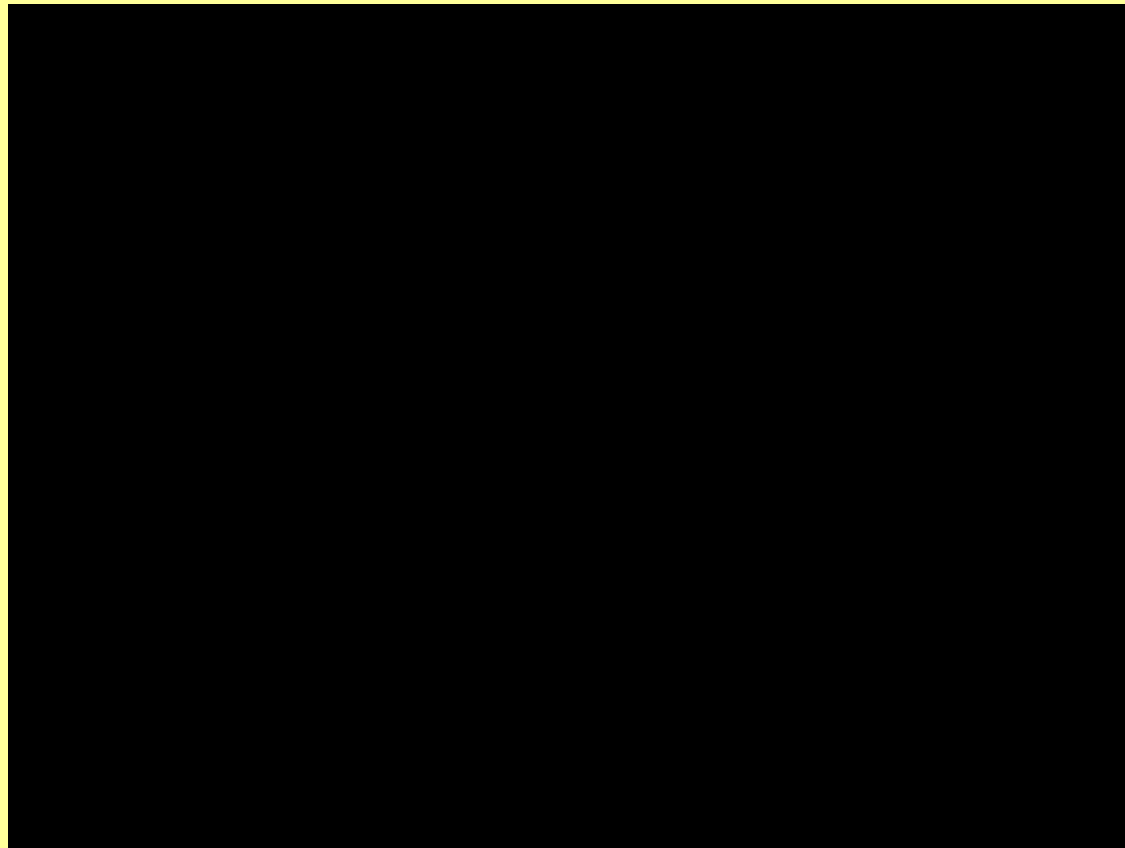
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Pumping to Increase Speed



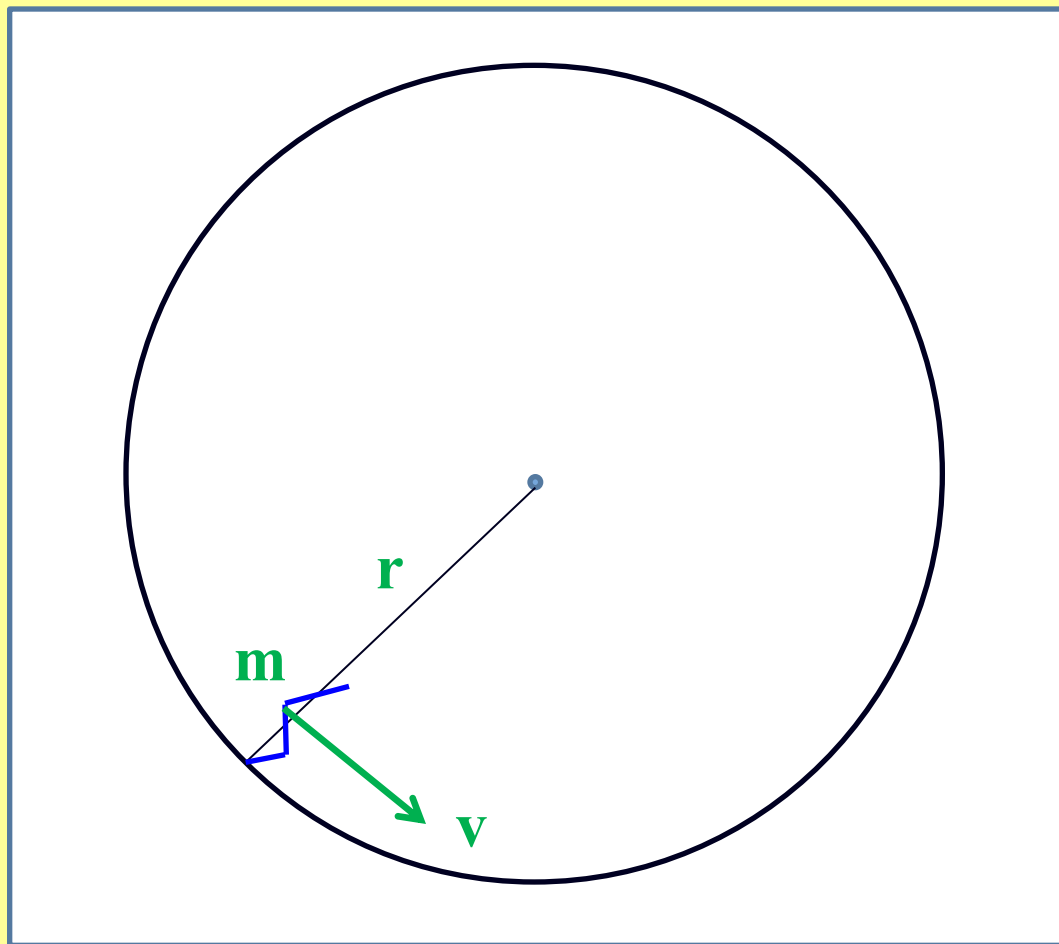
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Pumping to Increase Speed



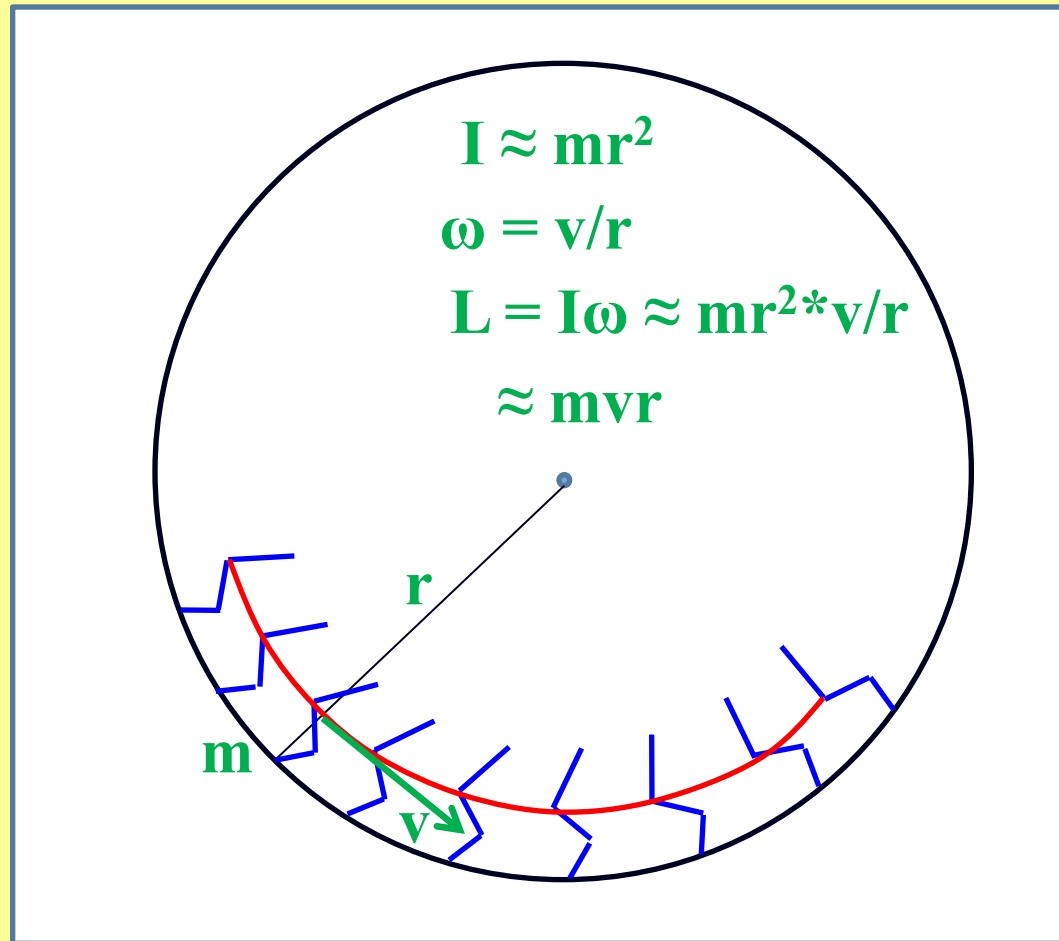
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Pumping to Increase Speed



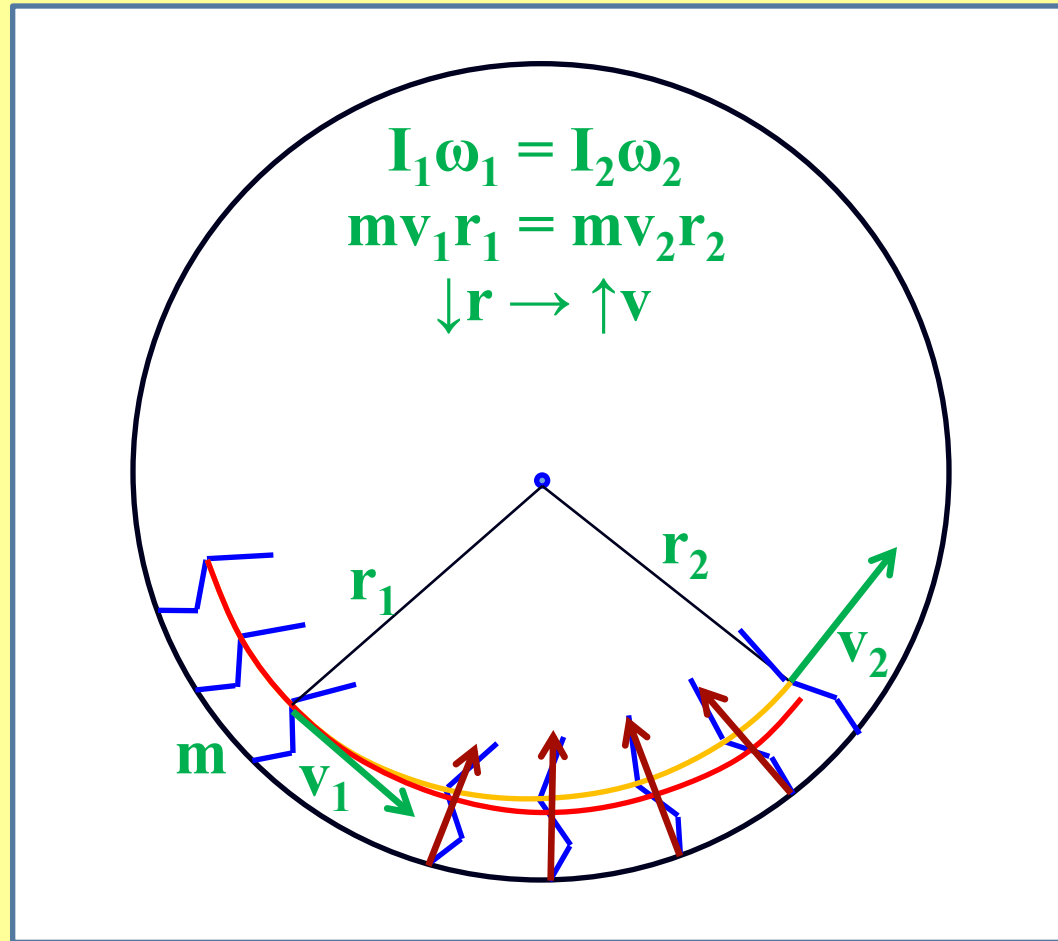
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Pumping to Increase Speed



Pumping to Increase Speed

- Pump up and rock back at point of highest normal force.
- Pump down and rock forward at point of lowest normal force.
- $\Delta KE = Fd$

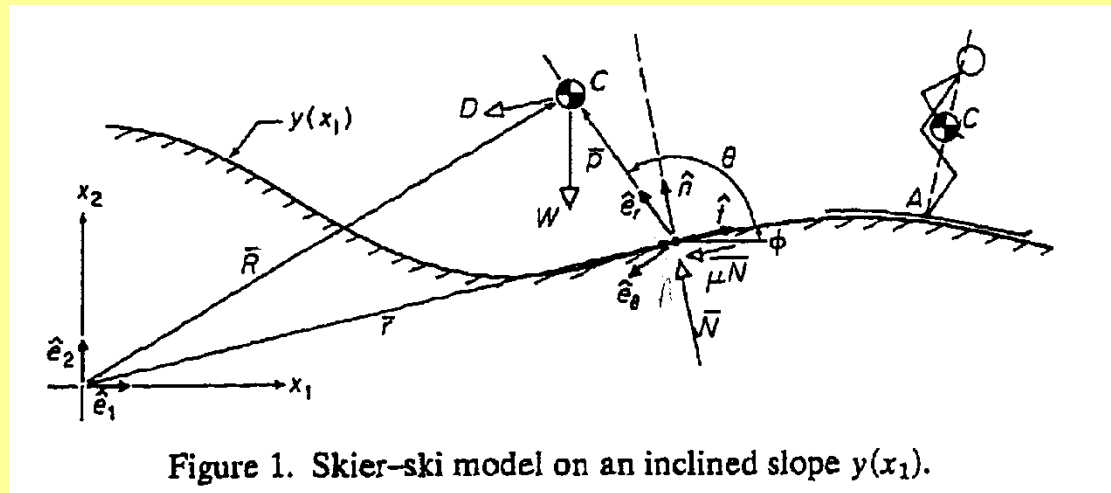


Figure 1. Skier-ski model on an inclined slope $y(x_1)$.

(Mote & Louie, 1983)

Pumping to Increase Speed

- Pump up and rock back at point of highest normal force.
- Pump down and rock forward at point of lowest normal force.

Hoff (1997): 5 – 10 % improvement in performance time when pumping in undulating terrain.

→ $\Delta KE = Fd$

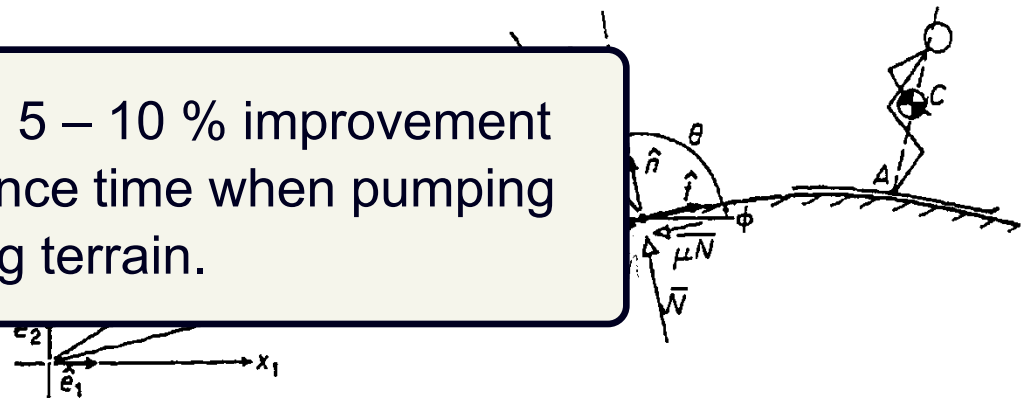


Figure 1. Skier-ski model on an inclined slope $y(x_1)$.

(Mote & Louie, 1983)

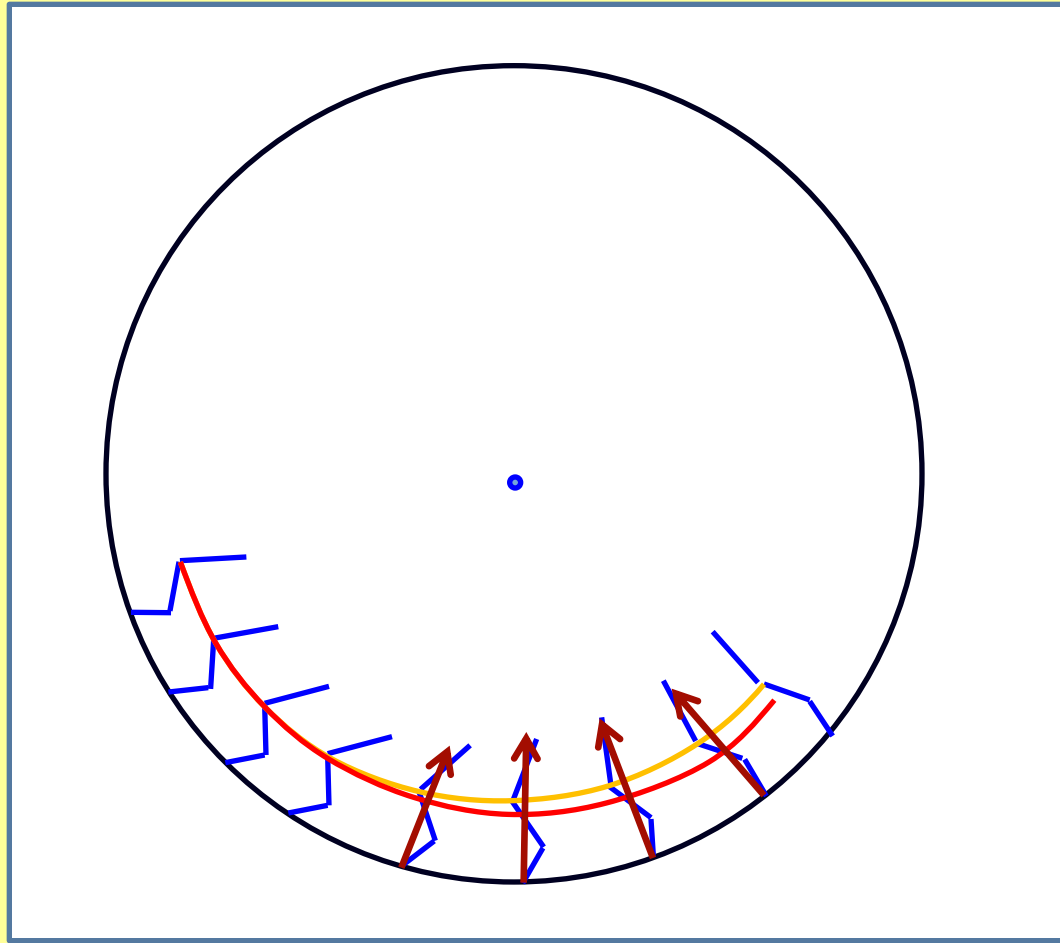
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Pumping to Increase Speed



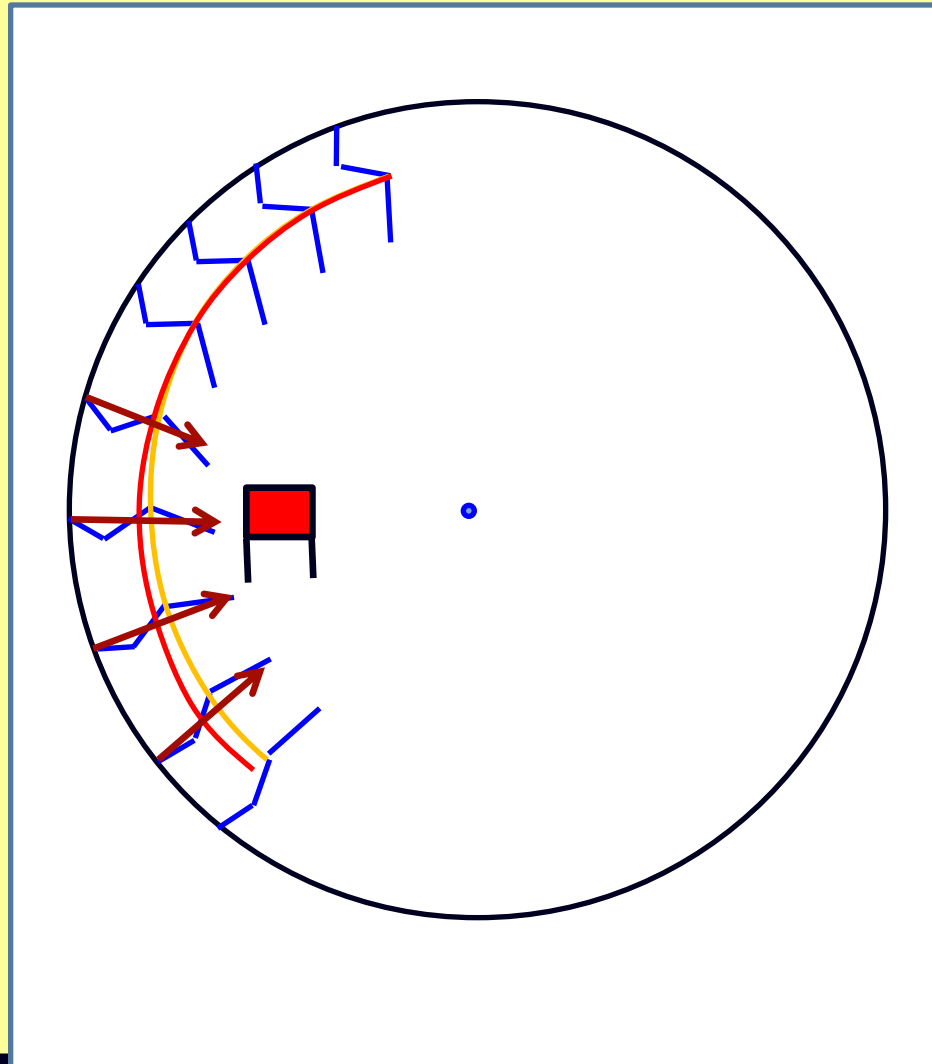
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Pumping to Increase Speed



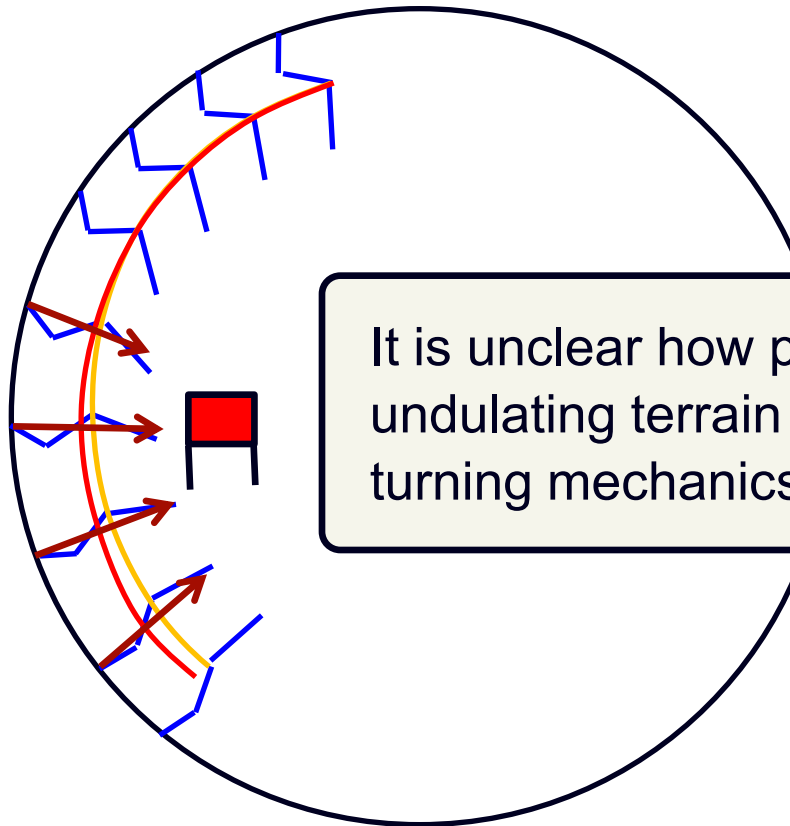
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Pumping to Increase Speed



It is unclear how pumping in undulating terrain might transfer to turning mechanics.

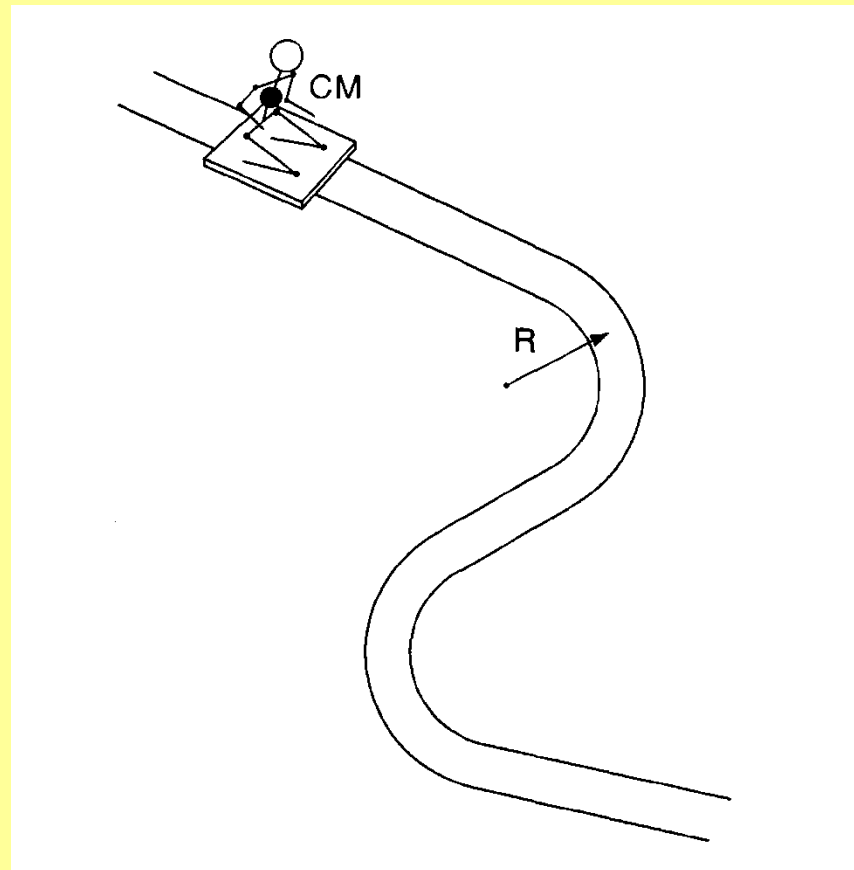
LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Pumping to Increase Speed



(Lind & Sanders, 2004)

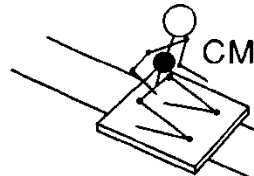
LATERAL
ACTIONS

ROTARY
ACTIONS

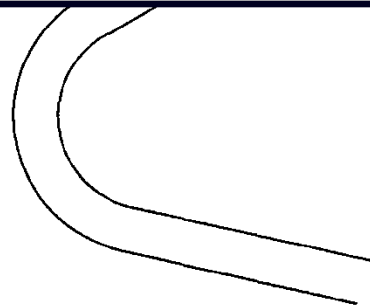
VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Pumping to Increase Speed



Supej (1993): Theoretical models neglect friction.



(Lind & Sanders, 2004)

LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

Pumping to Increase Speed



Fore/Aft Actions

Those actions occurring predominantly in the skier's sagittal plane and whose goals include:

- Regulating the ski's turning behaviour.
- Balancing against the external forces.
- Regulating speed.

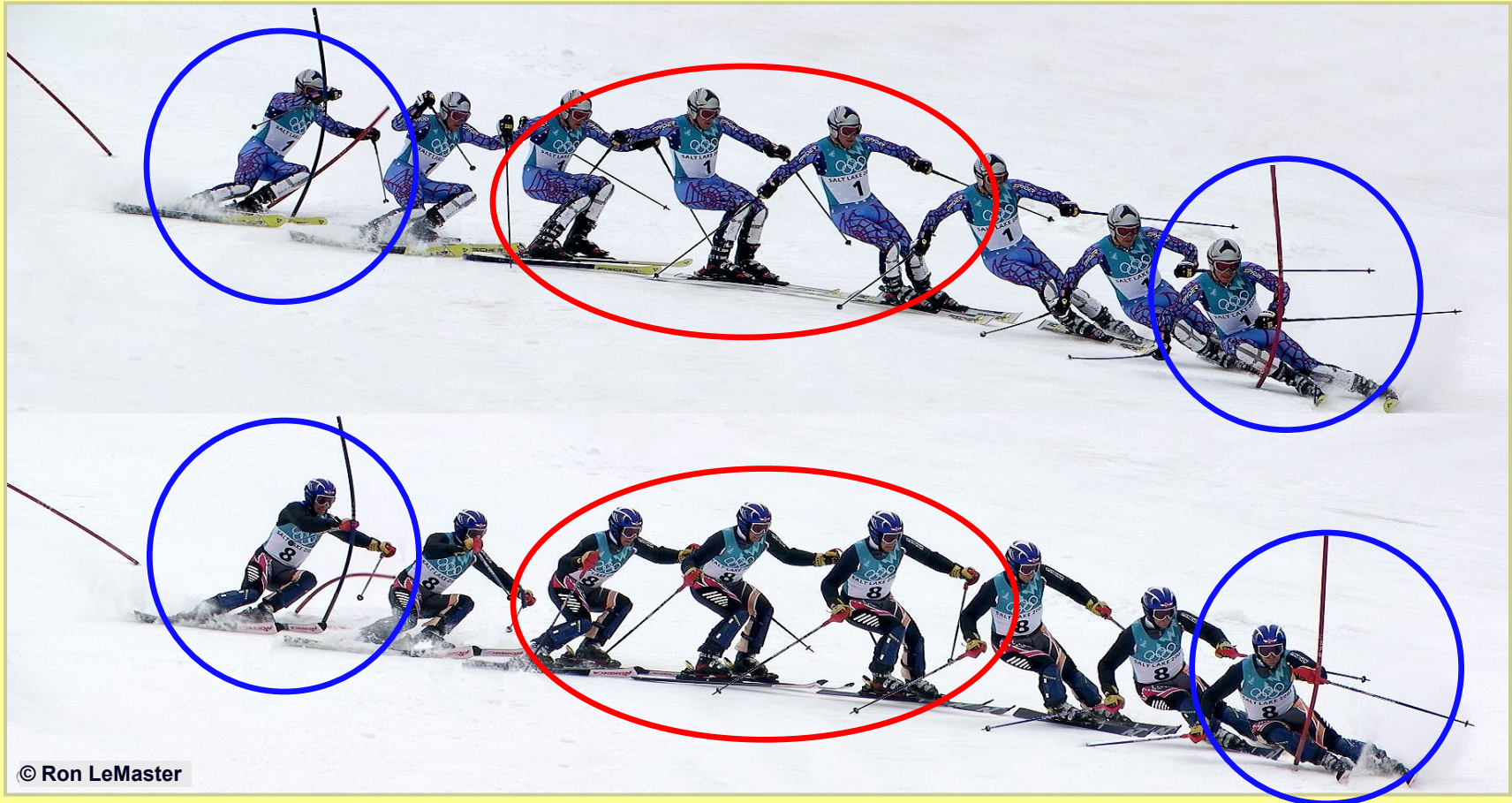


LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

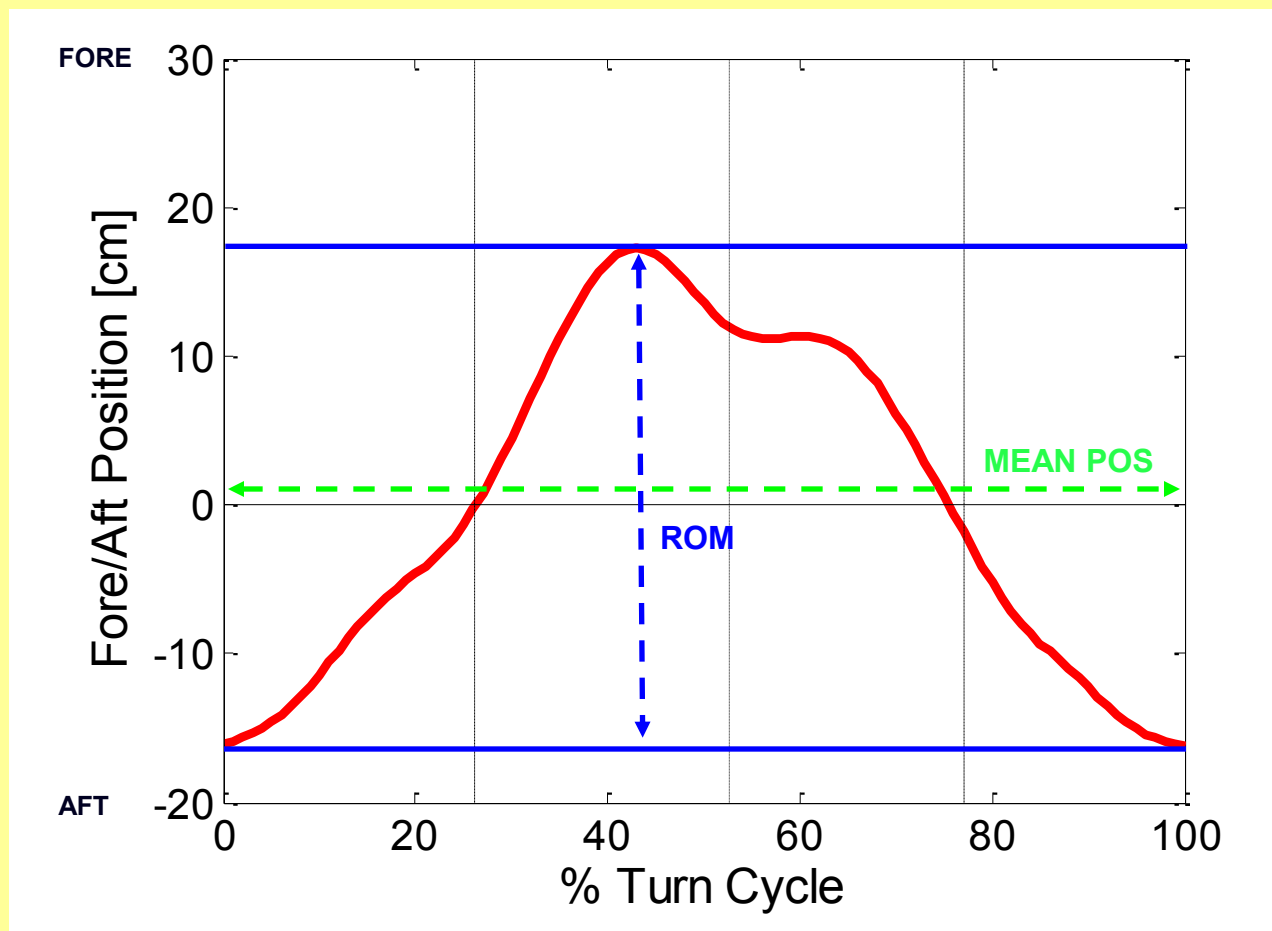


LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS



(Reid, 2010)

LATERAL ACTIONS

ROTARY ACTIONS

VERTICAL ACTIONS

FORE/AFT ACTIONS

	10 m Course Time [sec]		13 m Course Time [sec]	
	rho	p	rho	p
Avg Position [cm]	.89	.02	.77	.07
ROM [cm]	.20	.70	.26	.62

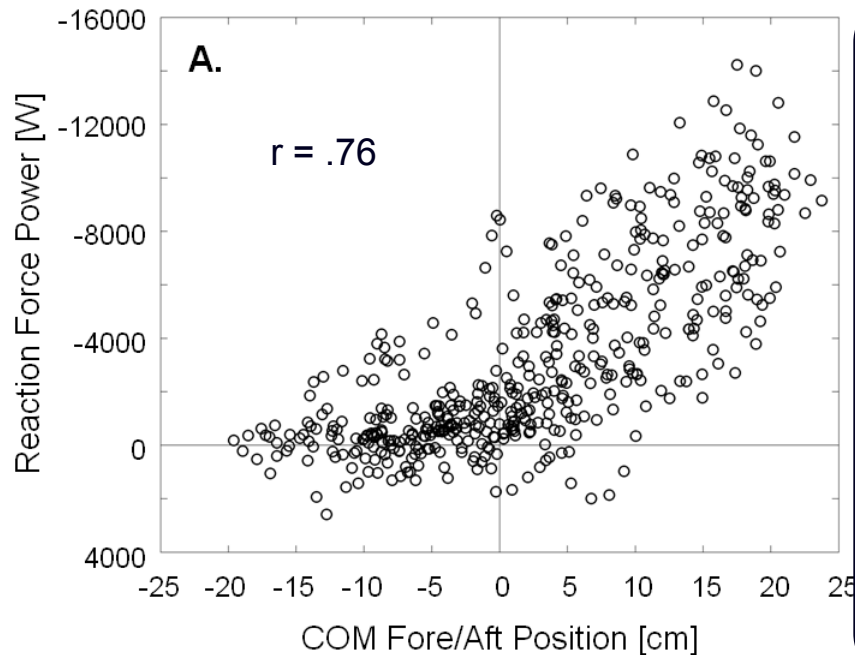
(Reid, 2010)

LATERAL
ACTIONS

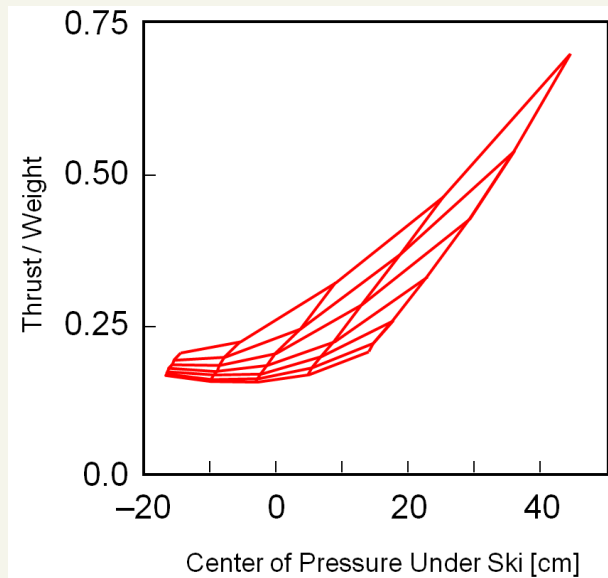
ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS



(Reid, 2010)



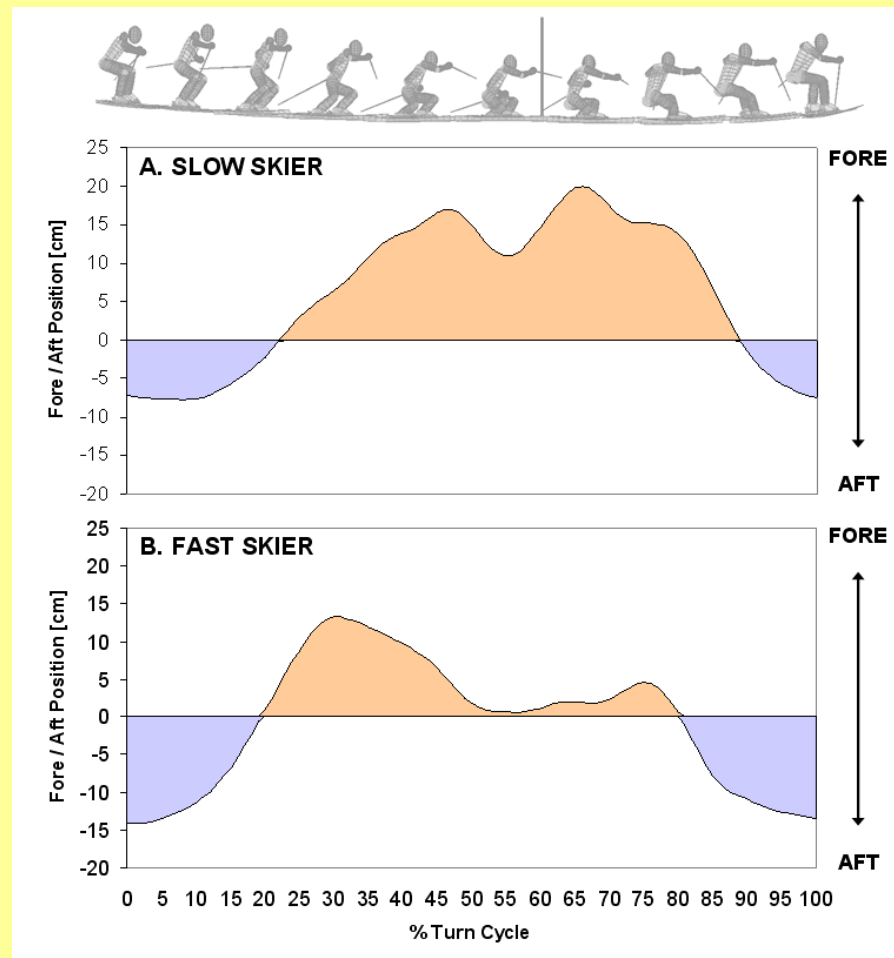
(Renshaw & Mote, 1989)

LATERAL ACTIONS

ROTARY ACTIONS

VERTICAL ACTIONS

FORE/AFT ACTIONS



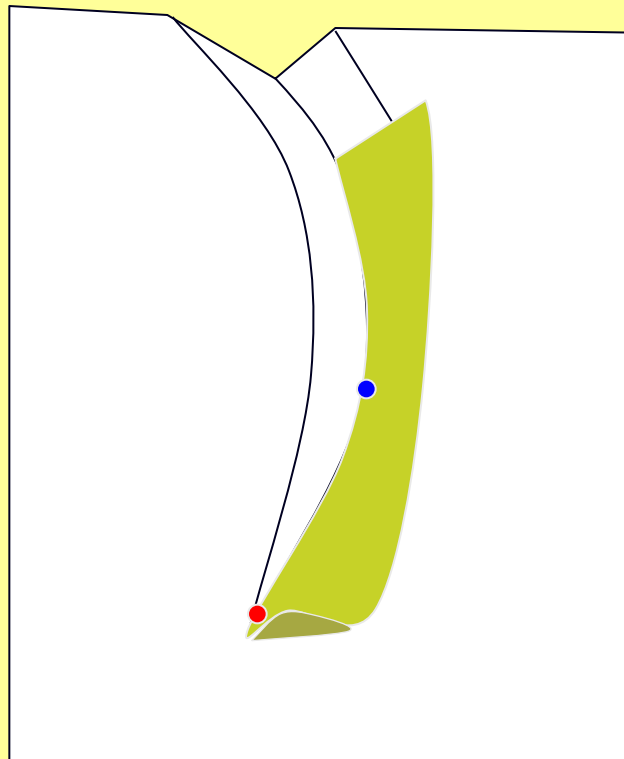
(Reid, 2010)

LATERAL
ACTIONS

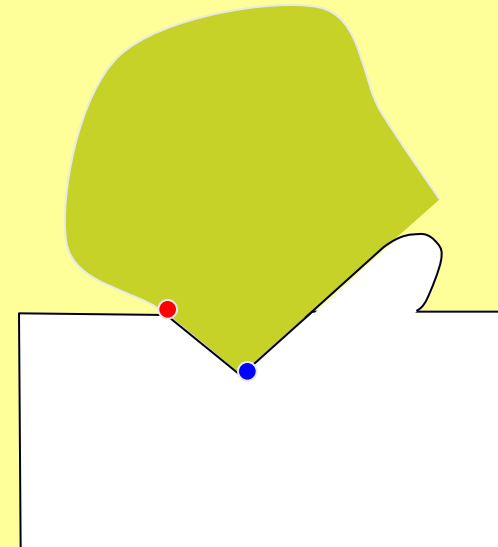
ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS



(modified from Tatsuno *et al.*, 2007)



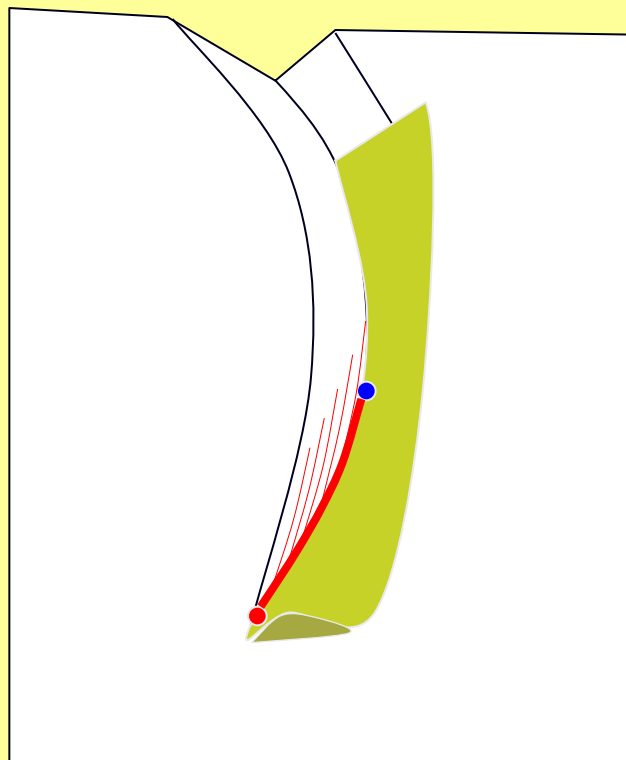
(modified from Federolf, 2005)

LATERAL
ACTIONS

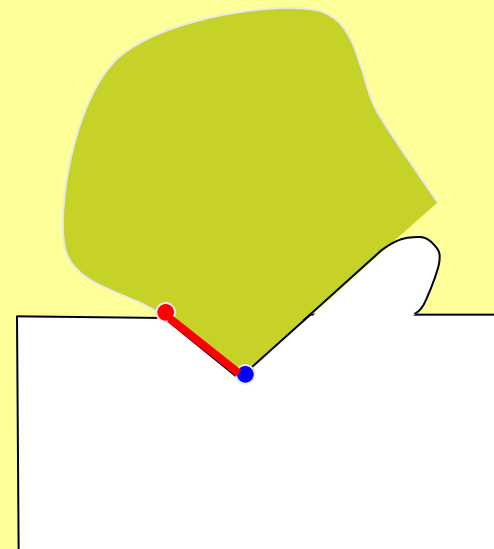
ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS



(modified from Tatsuno *et al.*, 2007)



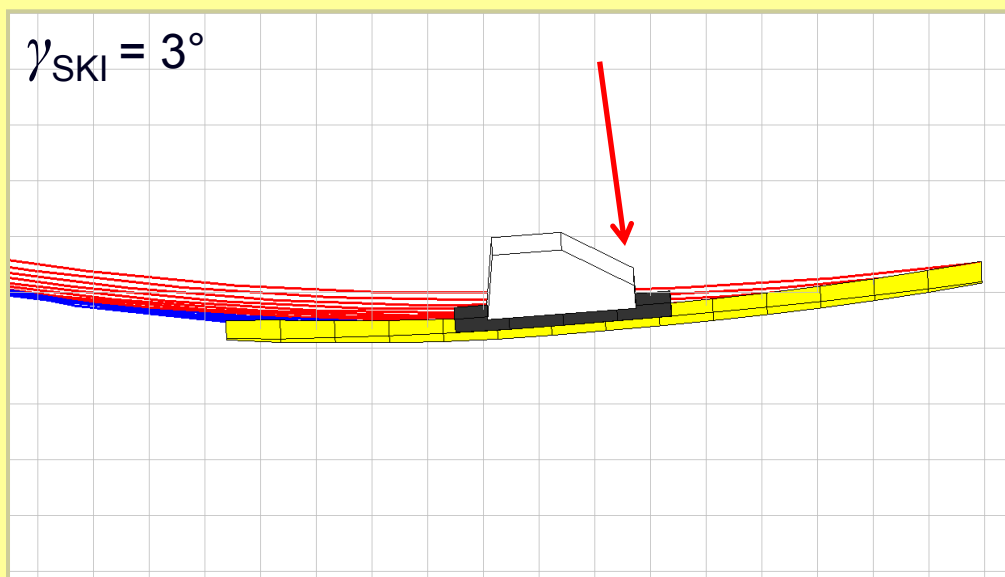
(modified from Federolf, 2005)

LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
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FORE/AFT
ACTIONS



(Reid, 2010)

LATERAL
ACTIONS

ROTARY
ACTIONS

VERTICAL
ACTIONS

FORE/AFT
ACTIONS

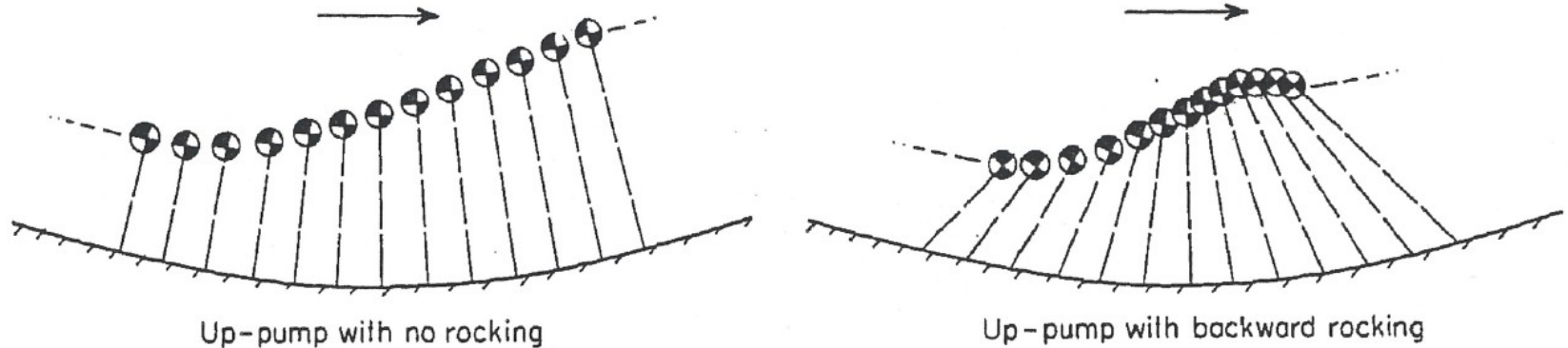


Figure 8. Center of mass trajectory during pumping with and without rocking.

(Mote & Louie, 1983)

Thank you!