

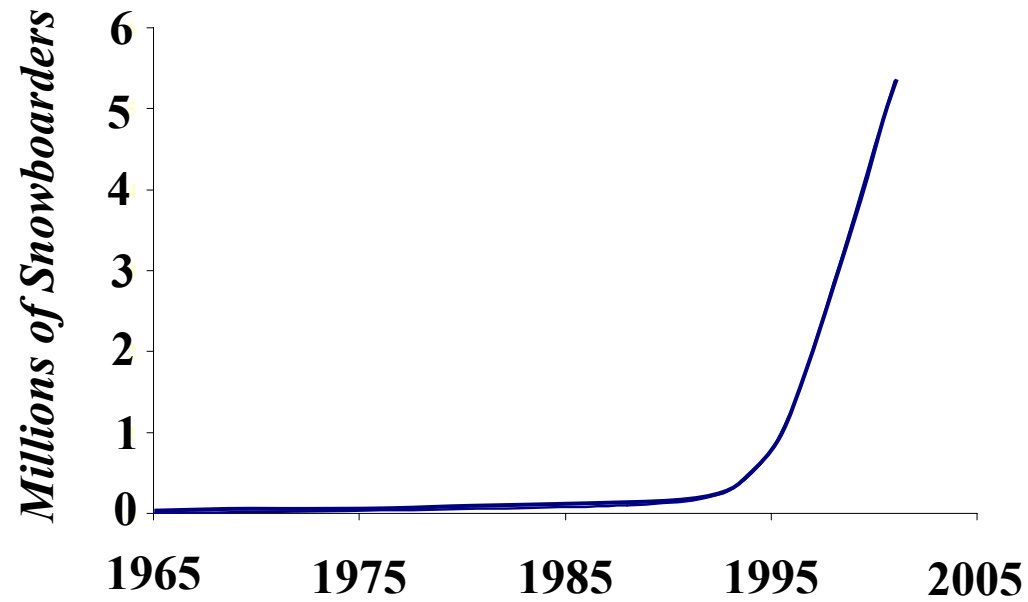
# Snowboard Design



Sarah M. Brennan

Advisors: Prof. László P. Kollár  
Prof. George S. Springer

# Growth of Snowboarding



# The Snowboarder



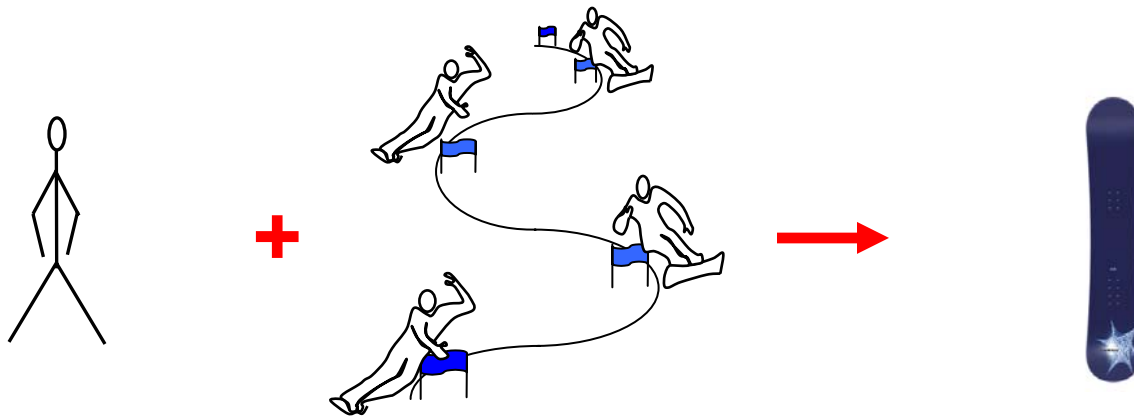
# Desired Features

Snowboarders want a snowboard that is:

- ◆ Fast
- ◆ Within skill level
- ◆ Safely with ease
  
- ◆ Attractive
- ◆ Inexpensive

# The Need

## A METHOD for DESIGNING snowboards



- ◆ Snowboarder

Height  
Weight  
Skill level

- ◆ Course

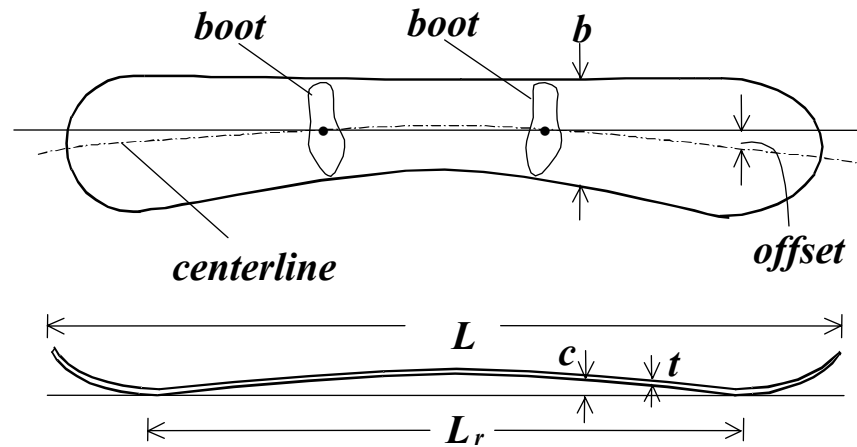
Snow  
Slope  
Path

- ◆ Snowboard

Fast  
Within skill level  
Safely with ease

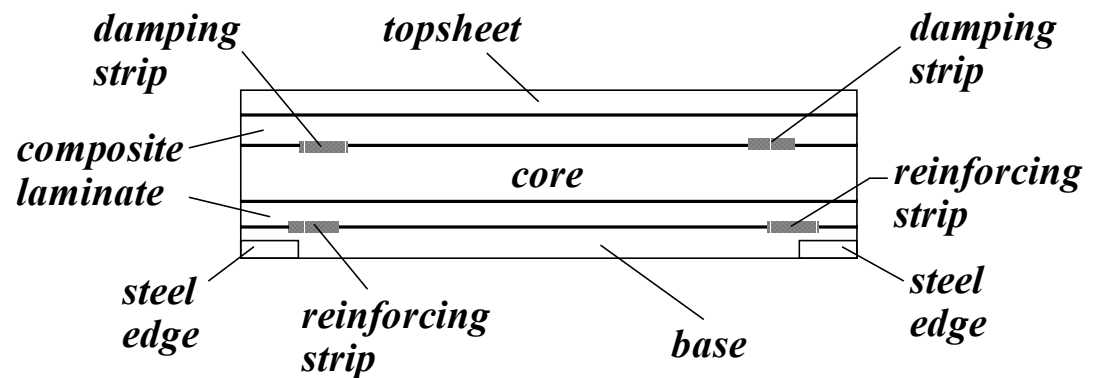
# Geometry and Construction

- ◆ Geometry



- ◆ Construction

- ◆ Materials, layup



# The Dream



- ◆ Snowboarder
  - ◆ Weight
  - ◆ Height
  - ◆ Skill level
- ◆ Snow conditions
- ◆ Slope
- ◆ Path



## “Best” Snowboard

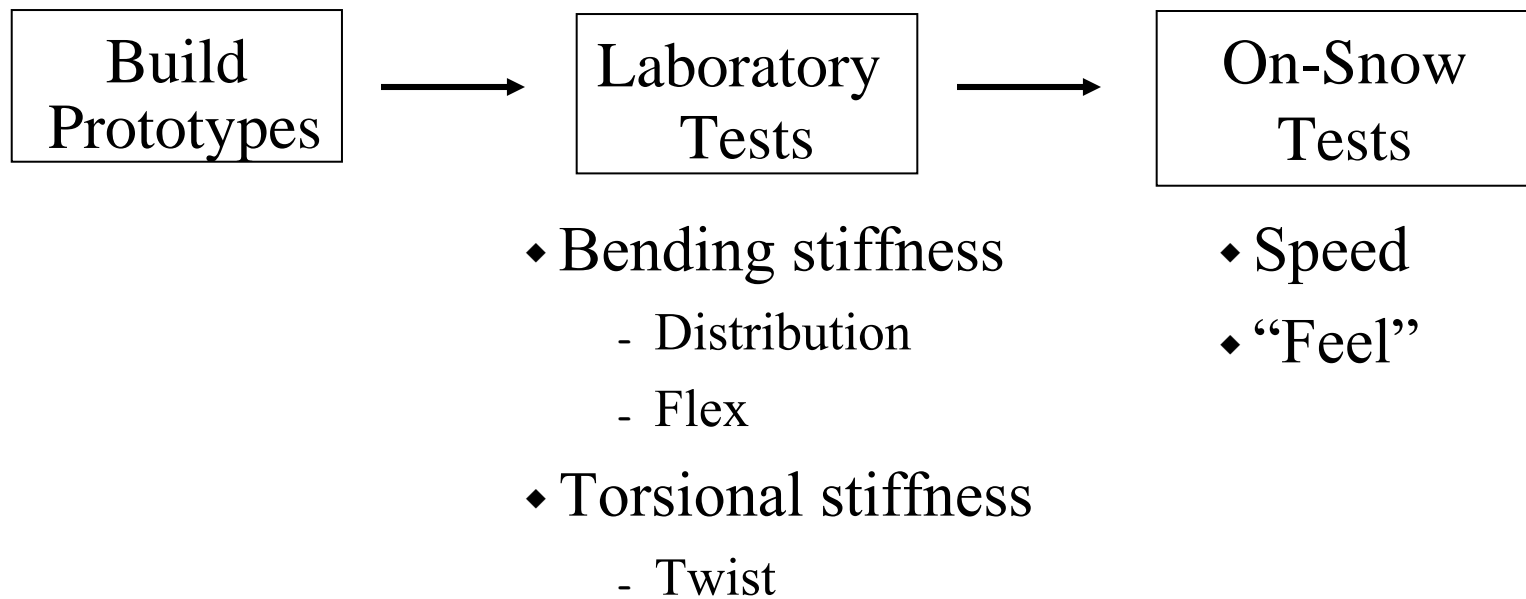
- ◆ Geometry
- ◆ Materials
- ◆ Construction

Fast

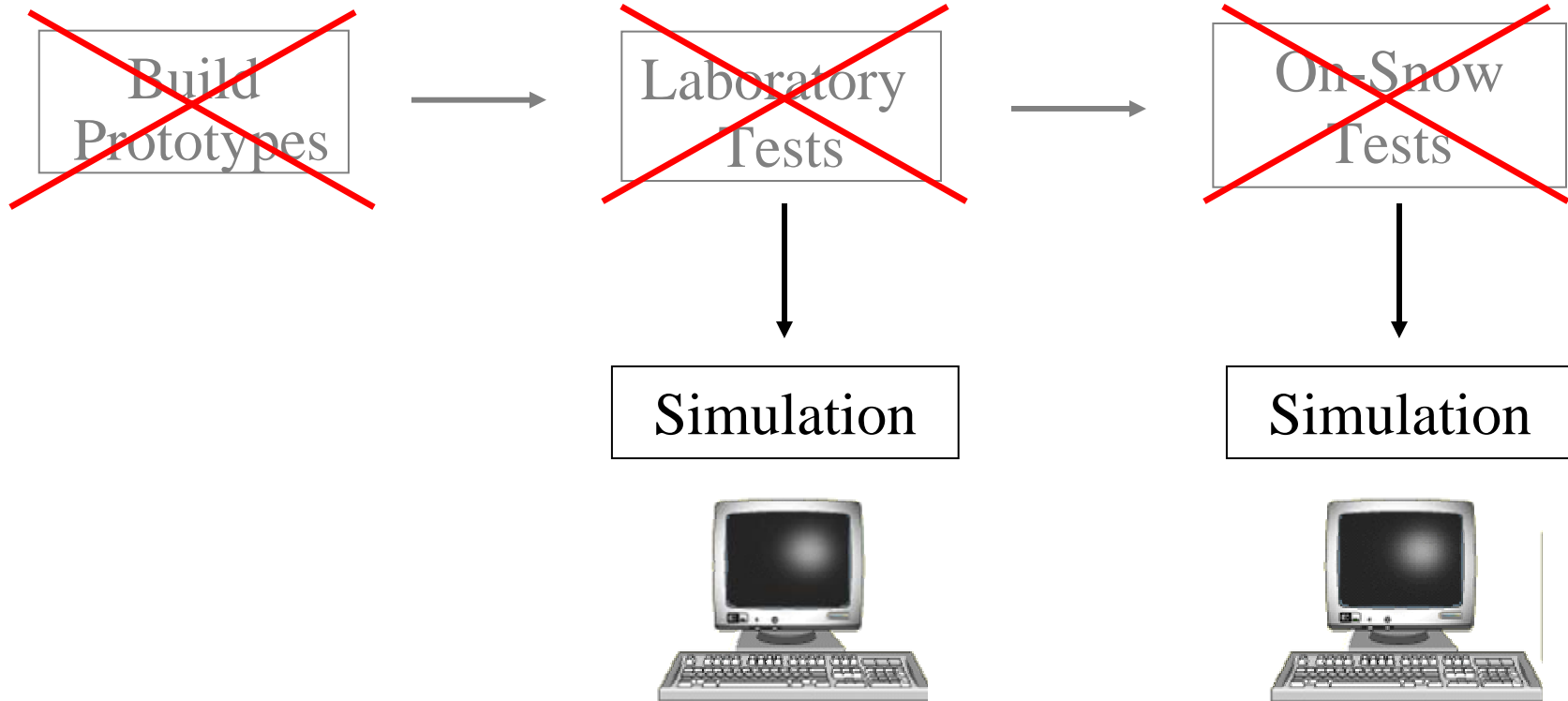
Within skill level

Safely with ease

# The Present Method



# Proposed Method: Virtual Tests



# Previous Work

## Snowboards

Sutton et al. 2000

- ◆ On-snow tests
  - Strain



- ◆ Laboratory tests
  - Strain
  - Boot forces

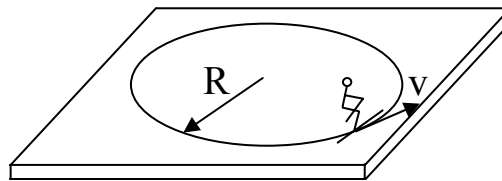


# Previous Work

## Skis

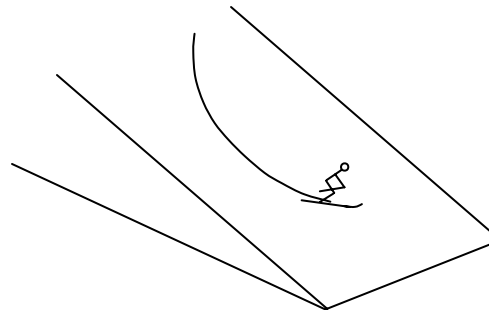
Mote et al. 1985 and 1991

- ♦ Horizontal surface
- ♦ Constant radius
- ♦ Constant speed
- ♦ Ski-metal, no camber



Nordt, Kollár, Springer 1999

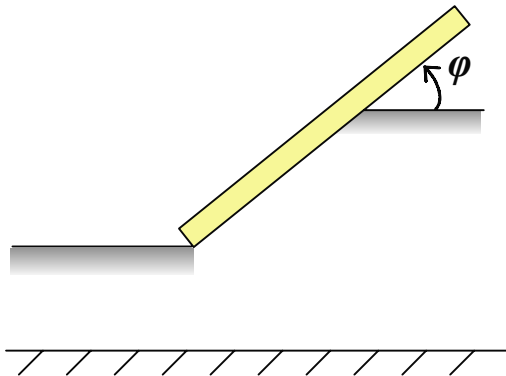
- ♦ Mechanical properties
- ♦ On-snow performance



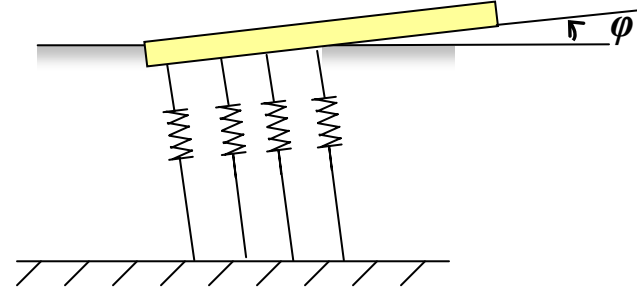
# Snowboard versus Ski

## Major differences between skis and snowboards

- ♦ 2 boots
- ♦ Unsymmetrical geometry, layup
- ♦ 2 turns
- ♦ Inertia forces
- ♦ Snow model



Brown and Outwater



Elastic foundation

# Virtual Tests: Mechanical Characteristics

~~Build  
Prototypes~~



~~Laboratory  
Tests~~



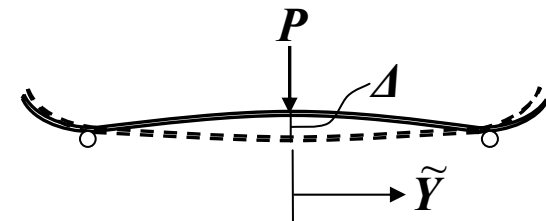
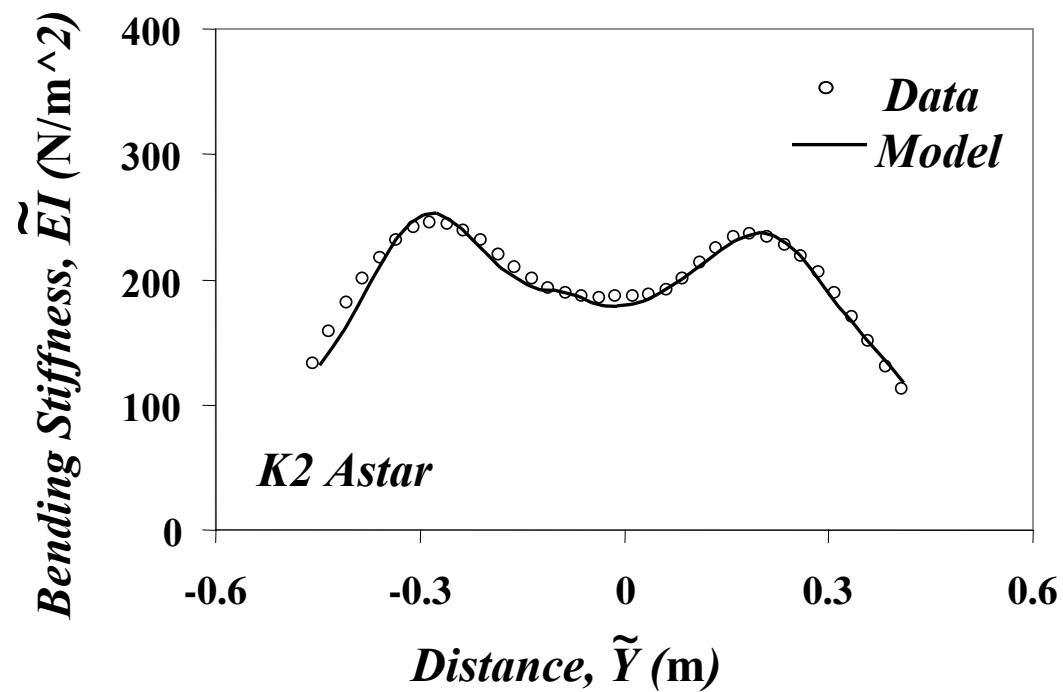
Simulation



FE with bend-twist coupling

- ◆ Bending Stiffness
  - Distribution
  - Flex
- ◆ Torsional Stiffness
  - Distribution
  - Twist

# Bending Stiffness and Flex



$$Flex = \frac{P}{\Delta}$$

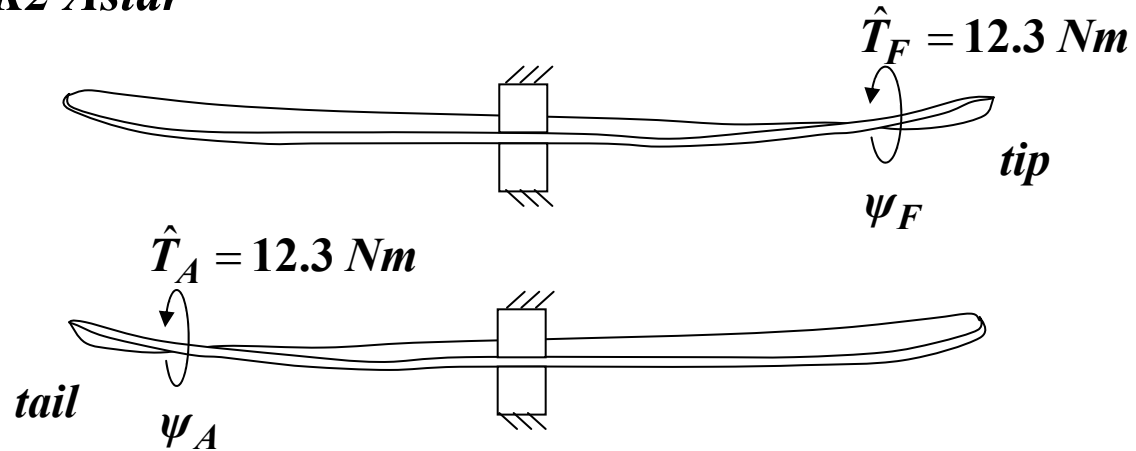
**Test**      6497 N/m

**Model**     6808 N/m

**Difference** 4.8%

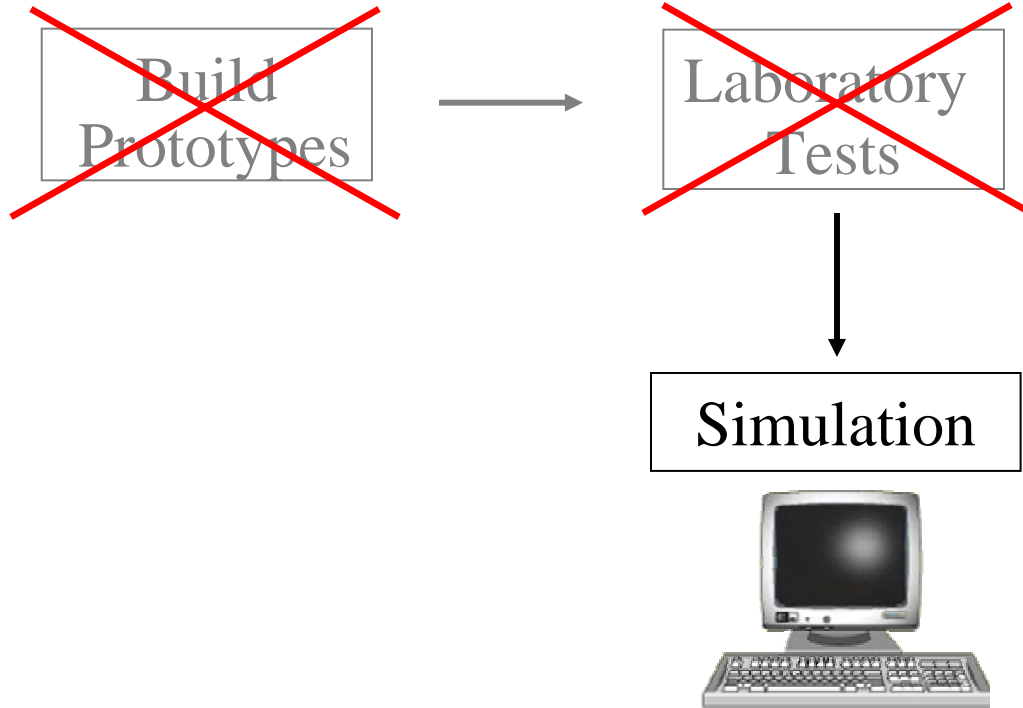
# Twist

*K2 Astar*



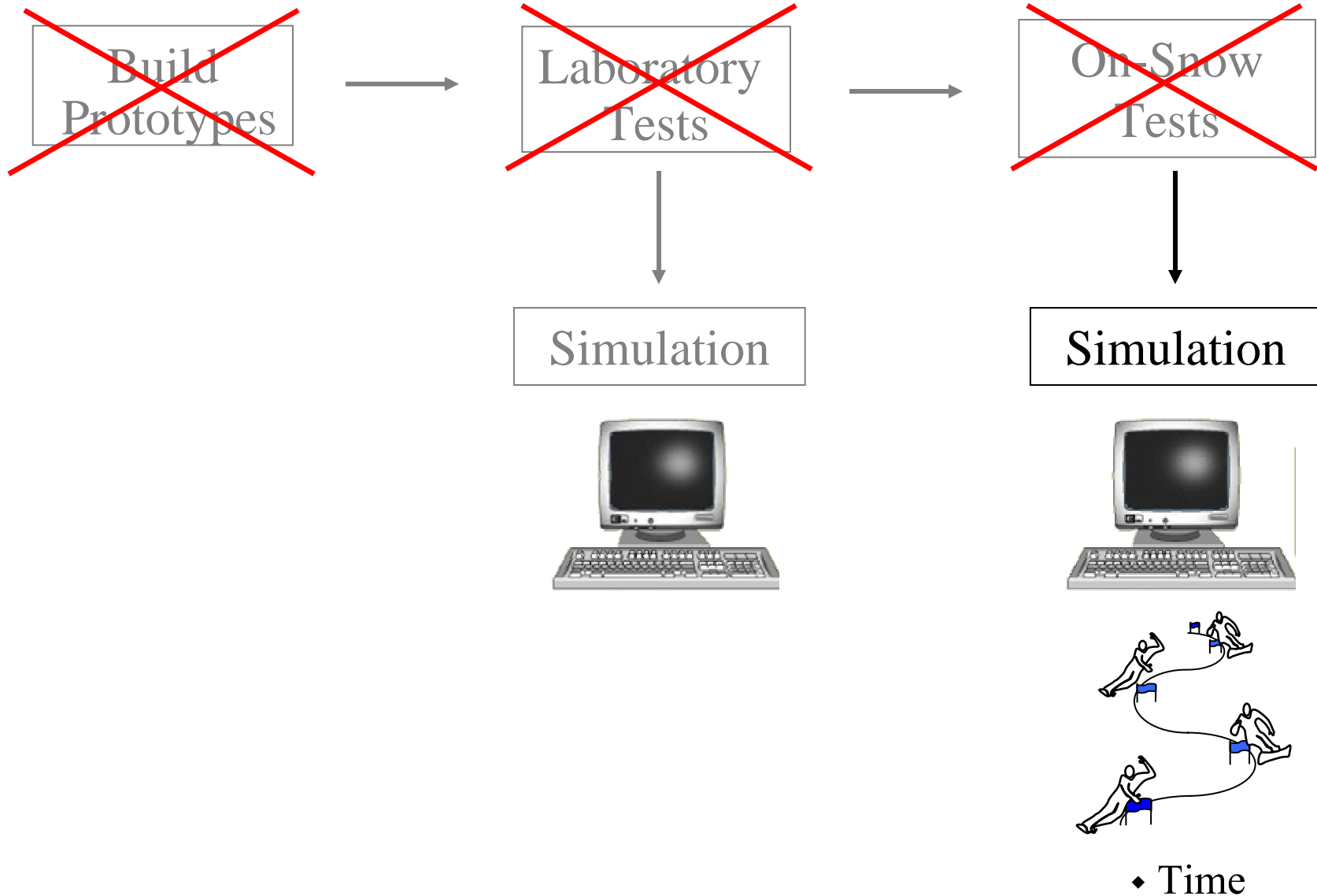
<b>Test</b>	<b>Model</b>	<b>Difference</b>
$\psi_F = 7.88^\circ$	$\psi_F = 7.76^\circ$	1.5%
$\psi_A = 7.05^\circ$	$\psi_A = 6.2^\circ$	12.0%

# Virtual Tests: Mechanical Characteristics



- ◆ Bending Stiffness
  - Distribution
  - Flex
- ◆ Torsional Stiffness
  - Distribution
  - Twist

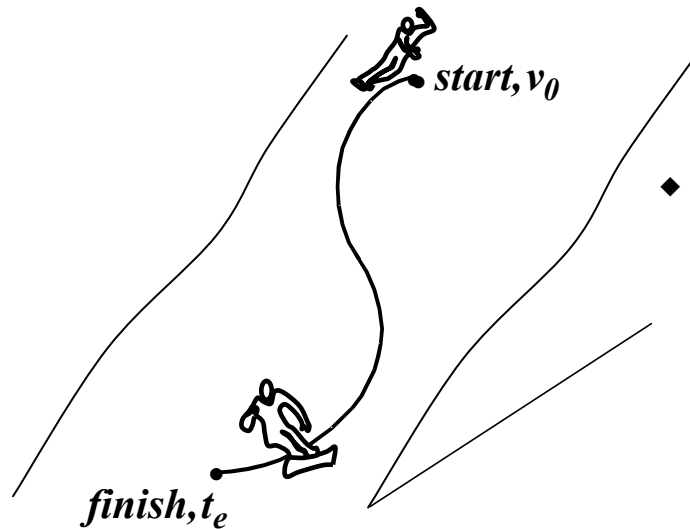
# Virtual Tests: On-snow Performance



# The Approach

Specify: Snowboard

- ◆ Snowboarder
  - ◆ Weight
  - ◆ Height
  - ◆ Skill level
- ◆ Snow
- ◆ Course
- ◆ Entering Speed

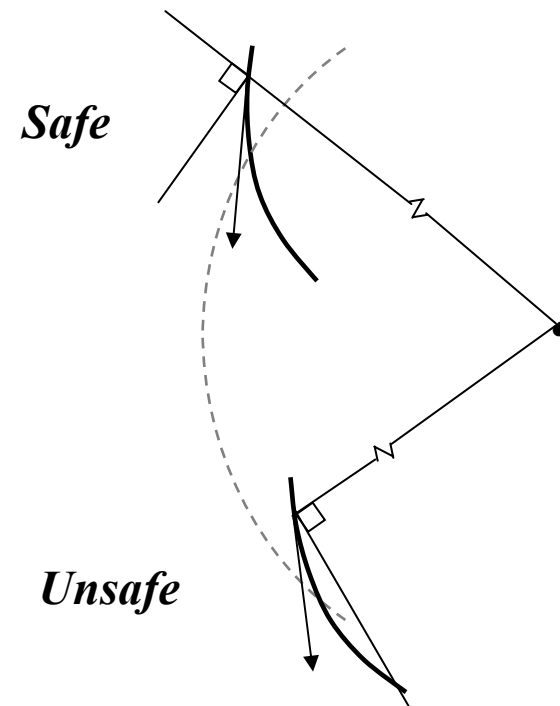
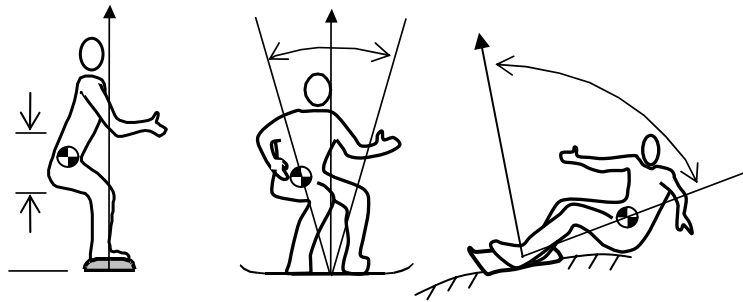


- ◆ Time to complete course
  - Within skill level
  - Safely with ease

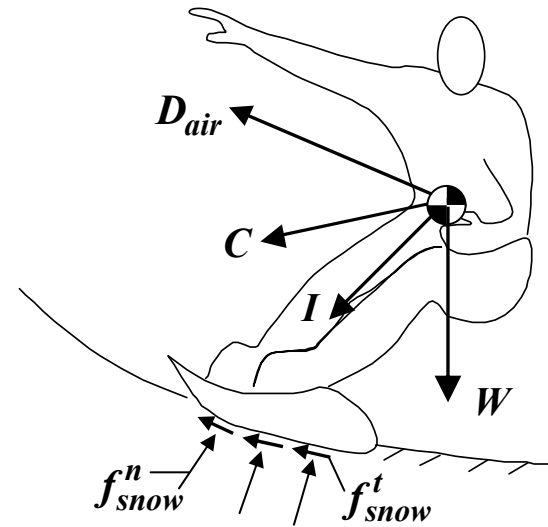
# Skill Level and Safely with Ease

Within prescribed range

- ◆ Speed  $< v_{\max}$
- ◆ Roll, yaw angles
- ◆ cg position



# Time to Complete the Course



Time  $\longrightarrow \Sigma F = m \frac{dv}{dt}$

# The Forces

- Weight

$$W = mg$$

- Centrifugal force

$$C = \frac{mv^2}{R}$$

- Drag

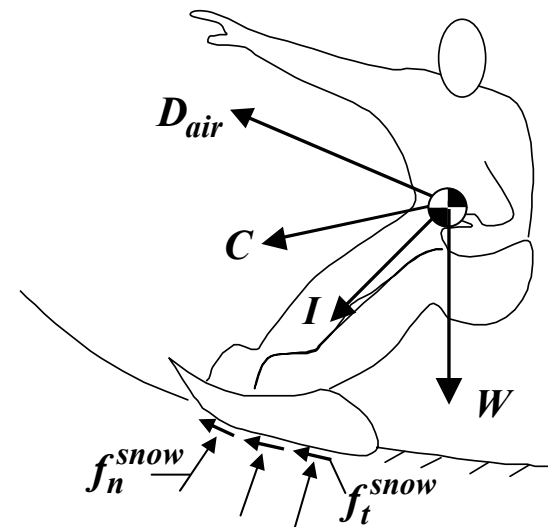
$$D_{air} = \frac{C_D A_F \rho_a v^2}{2}$$

- Inertia

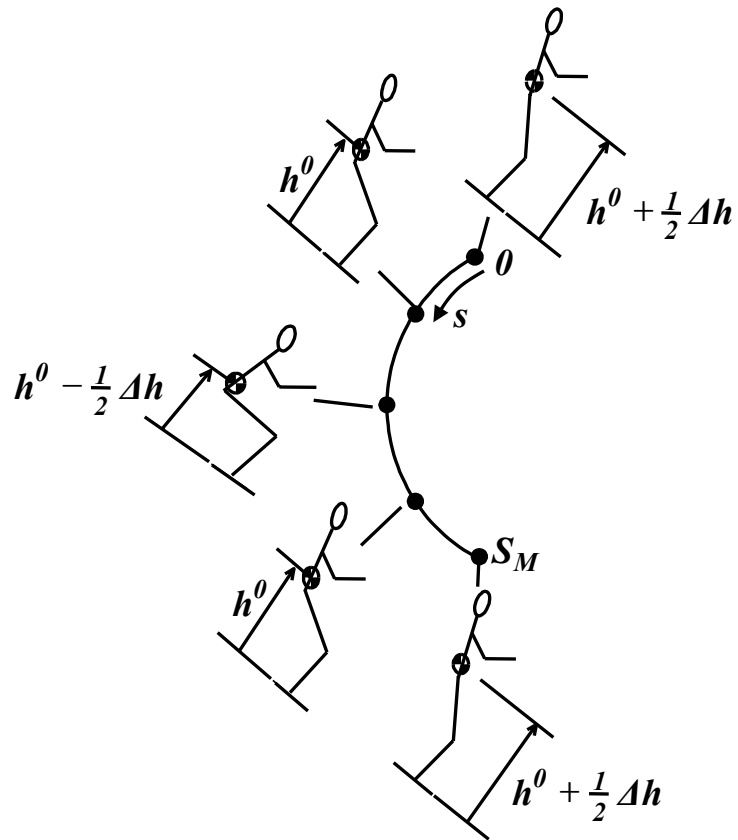
$$I = m \frac{d^2 h}{dt^2}$$

- Snow

$$f^{snow}$$

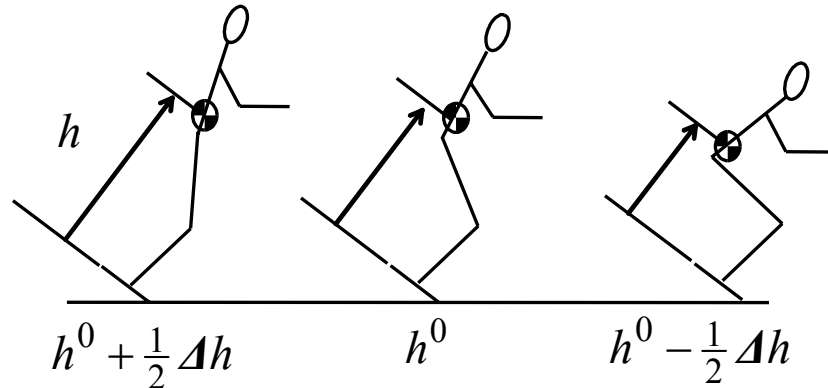


# Inertial Force



$$\Delta h \sim \cos\left(2\pi \frac{s}{S_M}\right)$$

# Inertia Force



$$I = m \frac{d^2 h}{dt^2}$$

$$h^0 = (0.4 \sim 0.6)H$$

$$\Delta h_{\max} = (0.2 \sim 0.3)H$$

$$\Delta h = (0.3 \sim 1.0) \left( \frac{v}{v_{\max}} \right) \cos \left( 2\pi \frac{s}{S_M} \right) \Delta h_{\max}$$

|                      |                      |  
 ability              speed              path

# The Forces

- Weight

$$W = mg$$

- Centrifugal force

$$C = \frac{mv^2}{R}$$

- Drag

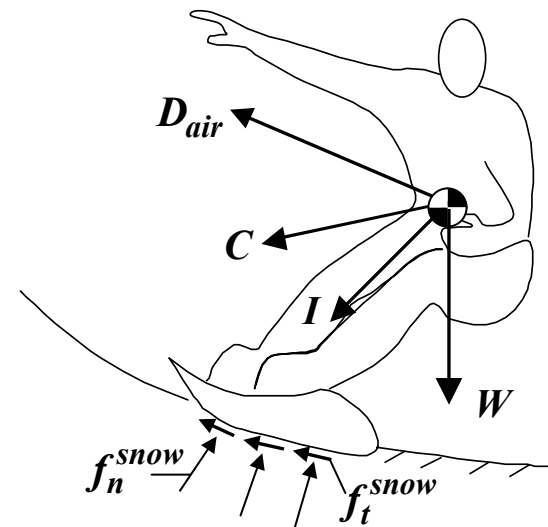
$$D_{air} = \frac{C_D A_F \rho_a v^2}{2}$$

- Inertia

$$I = m \frac{d^2 h}{dt^2}$$

- Snow

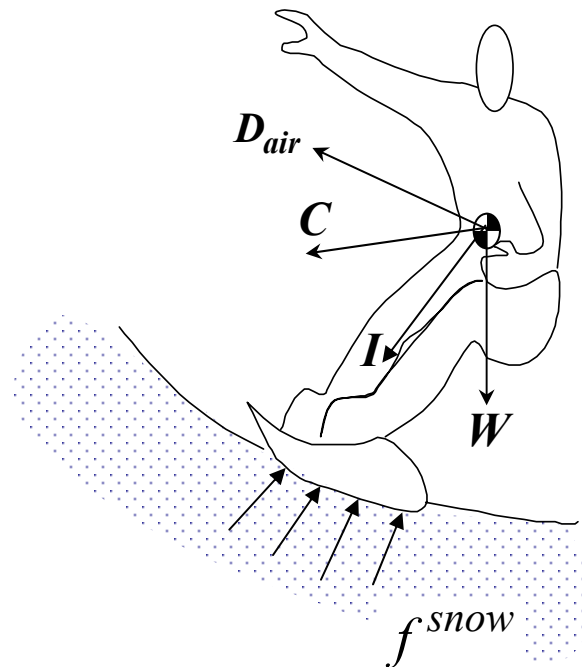
$$f^{snow}$$



# Snow Force

Force Method

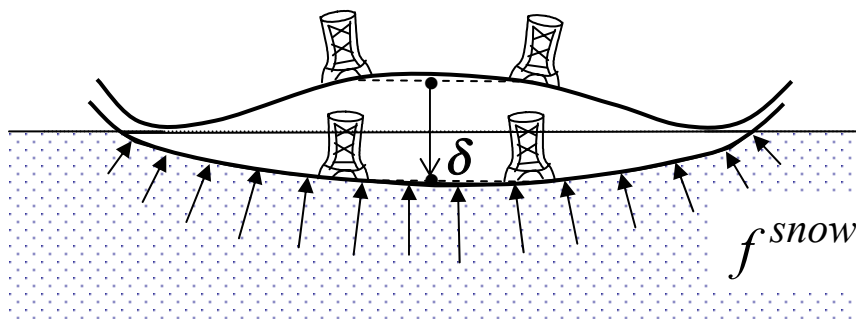
Displacement Method



Nordt, Kollar, Springer: Alpine skis

- ♦ non-linear
- ♦ large displacements
- ♦ contact problem

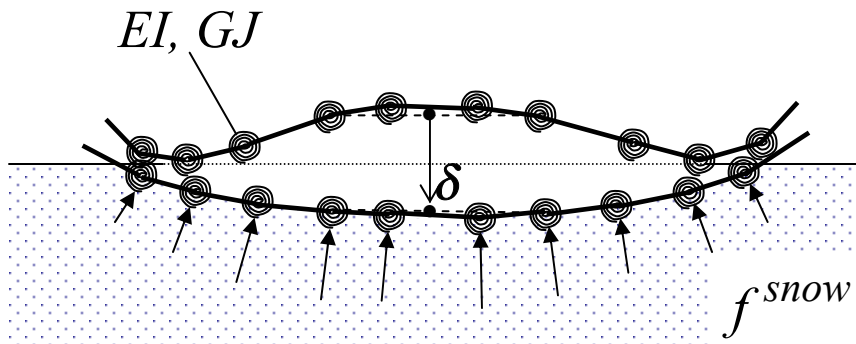
# Snow Force



pitch  
roll  
yaw  
depth

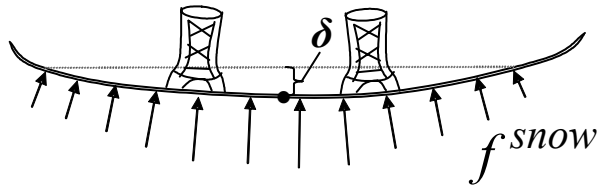
→

snow forces  
deformed shape



FE: incremental method  
with load correction

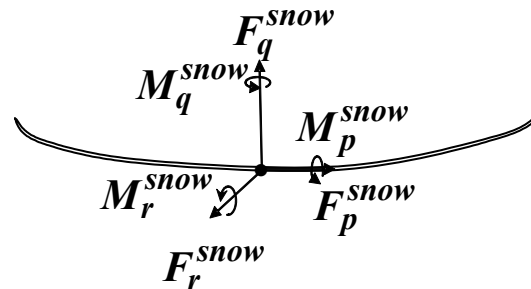
# Snow Force



Given: pitch  
roll  
yaw  
depth

Calculate: snow forces  
deformed shape

- ◆ Represent distributed snow force by equivalent forces and moments

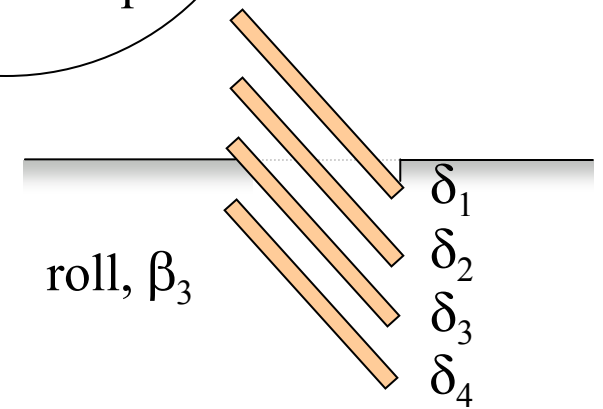
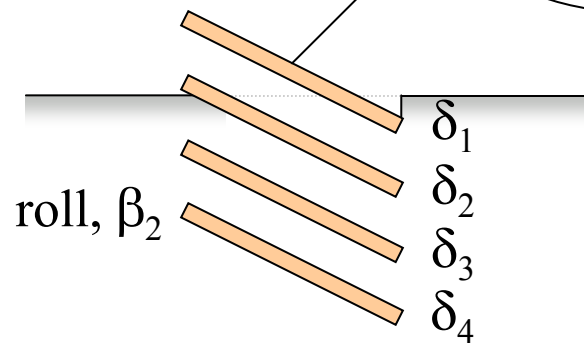
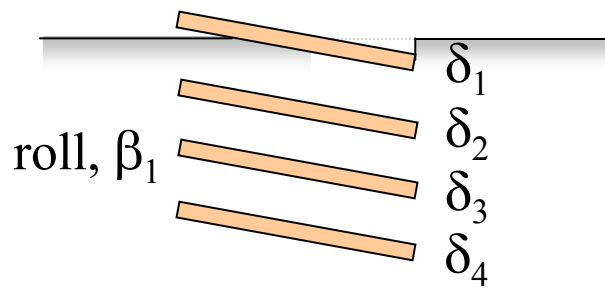
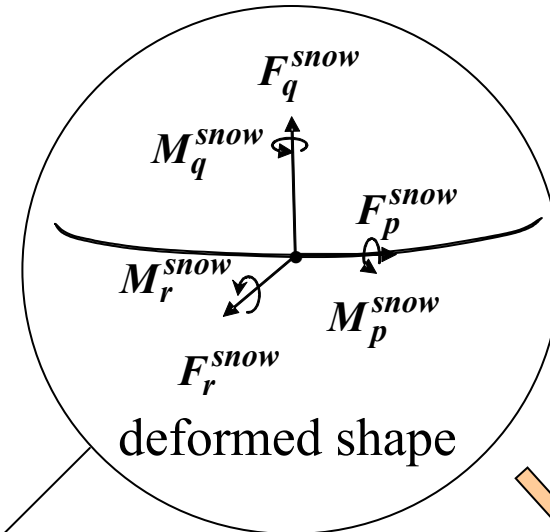


- ◆ Repeat for different values of pitch, roll, yaw

# The Making of the Library

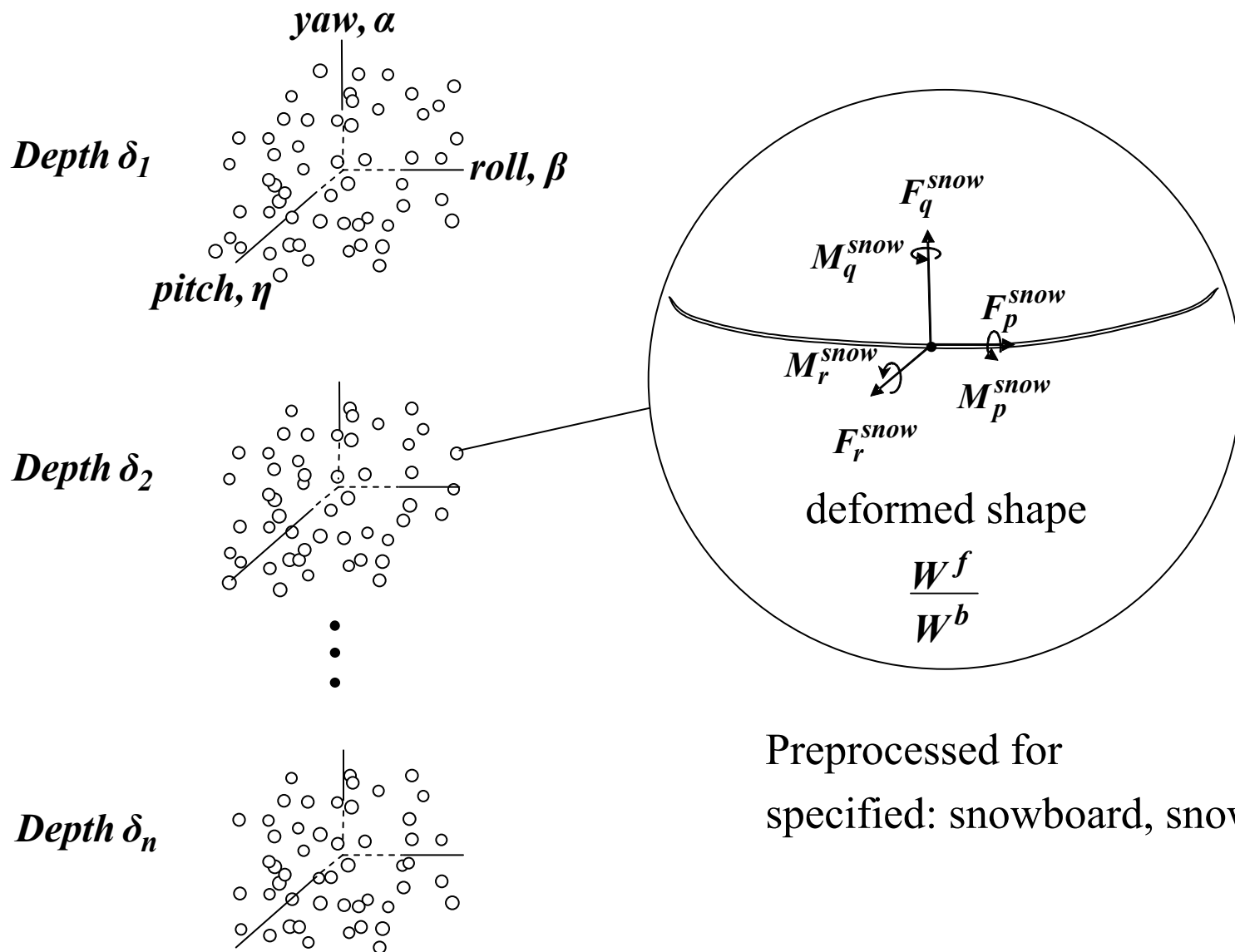
Specified: snowboard  
snow

Given : pitch  $\eta_1$ , yaw  $\alpha_1$

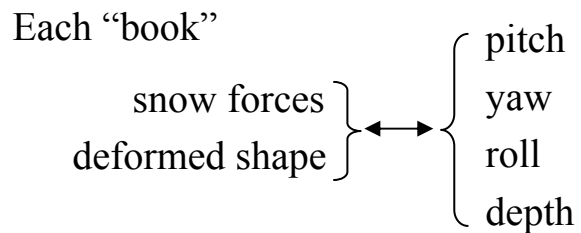
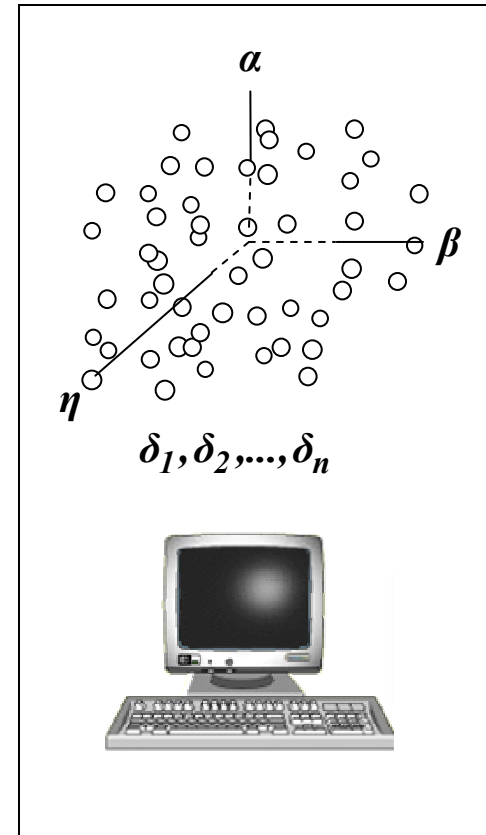
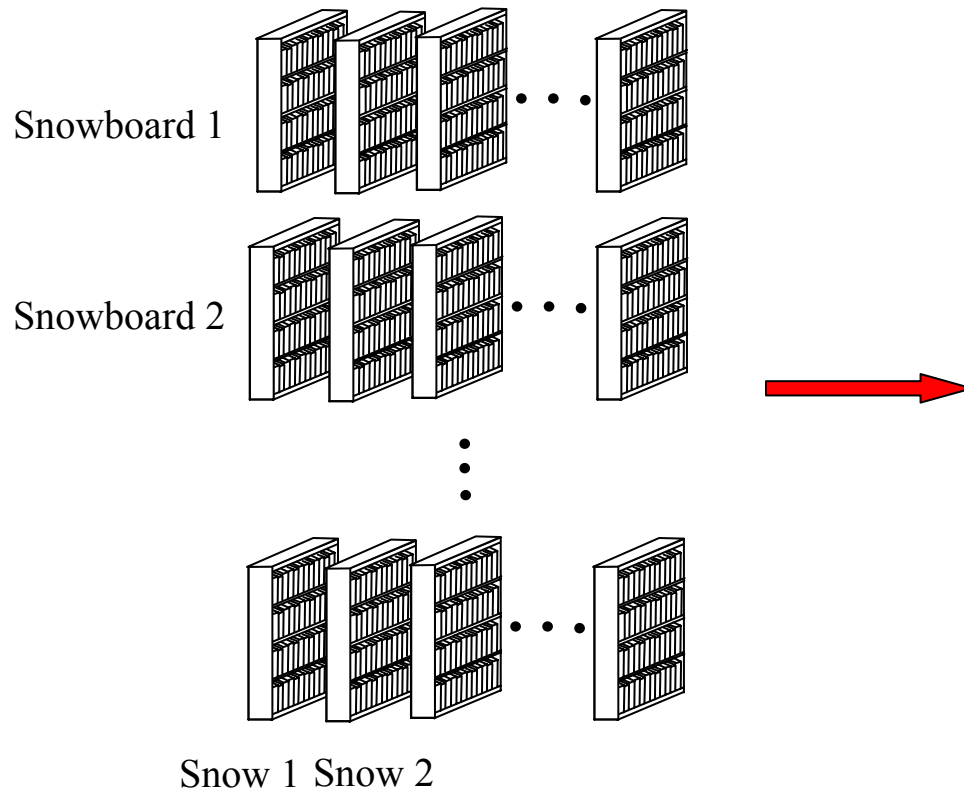


Repeat for different combinations of pitch and yaw

# The Library



# The Library



# Use of the Library

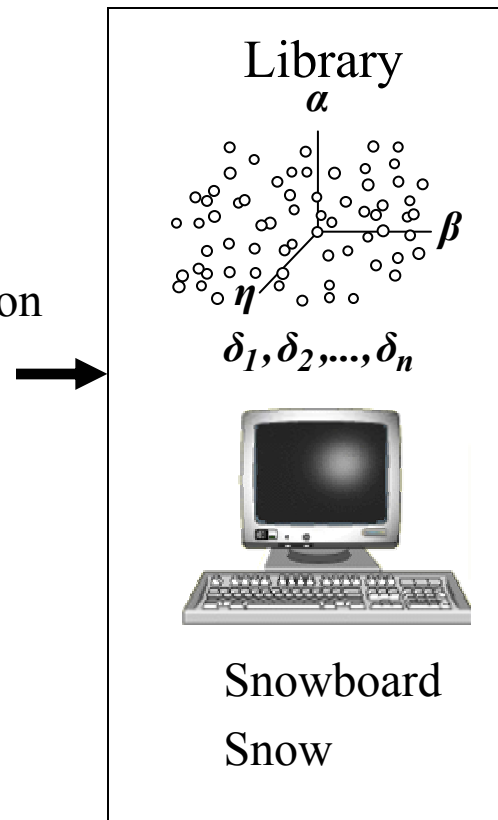
- ◆ Snowboarder

- Weight
- Height
- Skill level
- Weight distribution

- ◆ Course

- Slope
- Radii
- Turn length

- ◆ Entering Speed



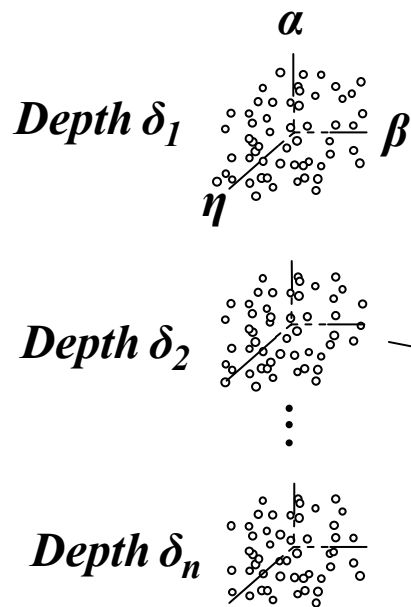
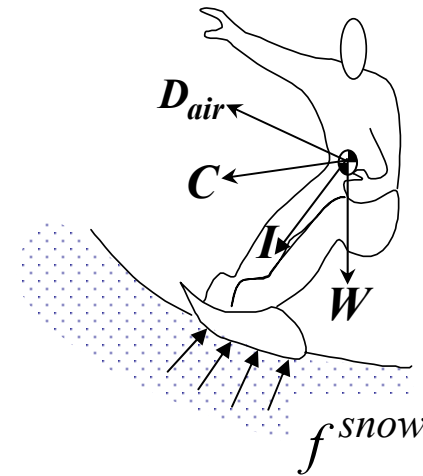
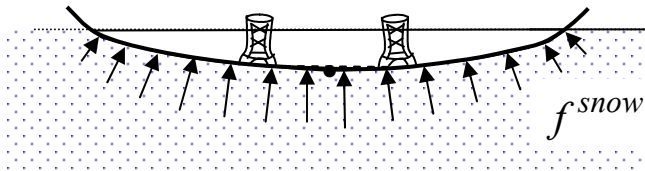
- ◆ Highest speed

Within skill level  
Safely with ease

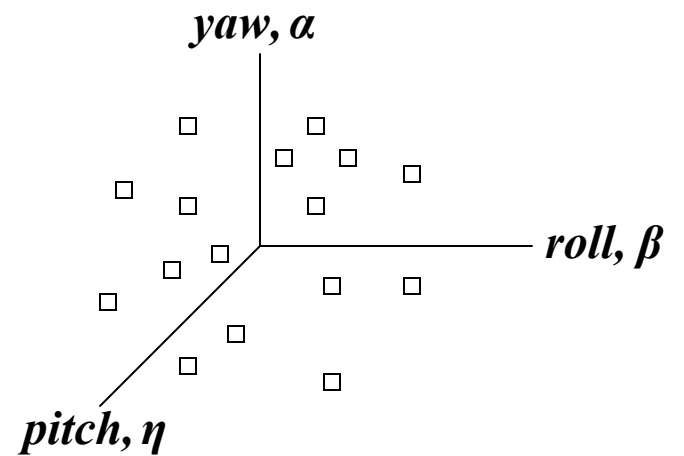
- ◆ Total Time



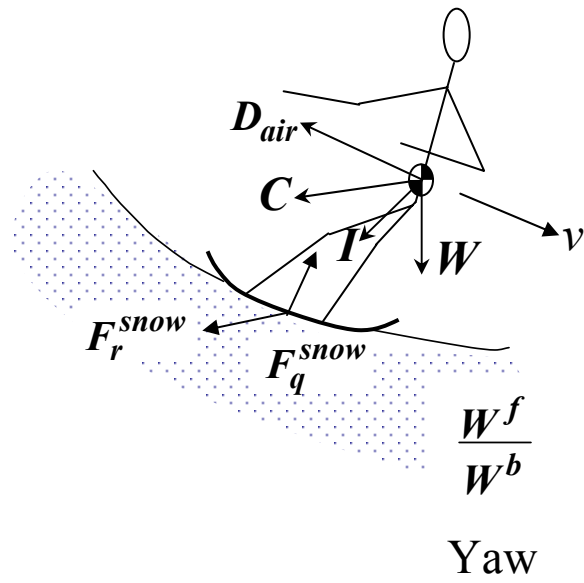
# Use of the Library



Relevant data set



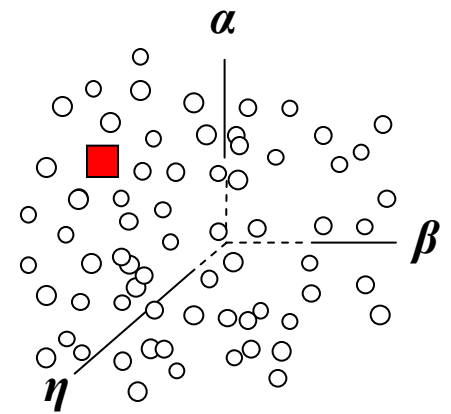
# Relevant Data Set



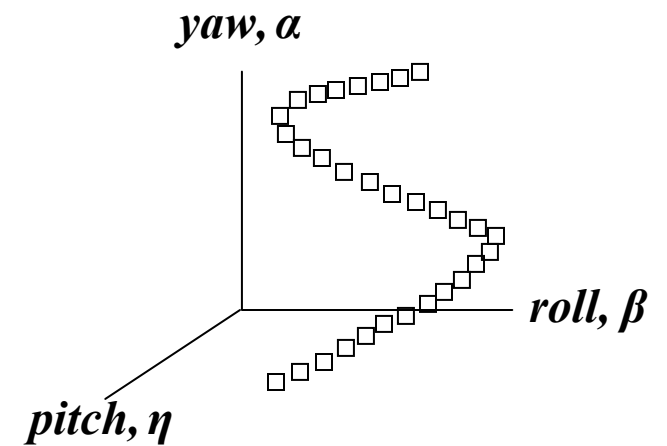
$$F_q^{snow} = -(W_q + I_q)$$

$$F_r^{snow} = -(W_r + I_r + C_r)$$

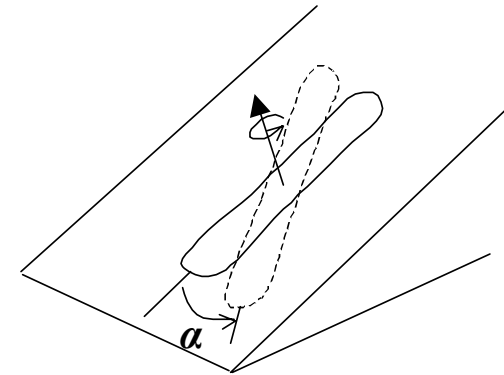
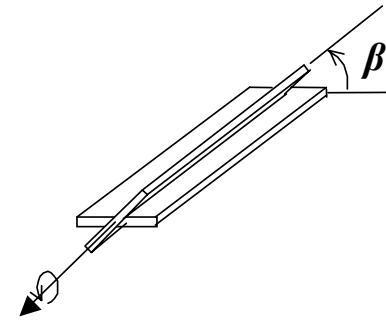
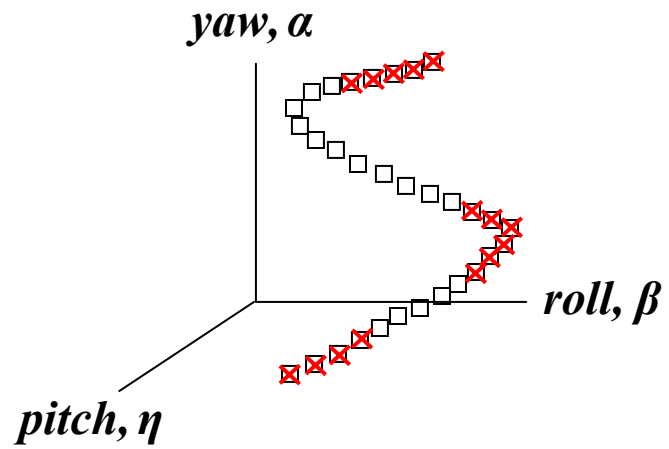
Library



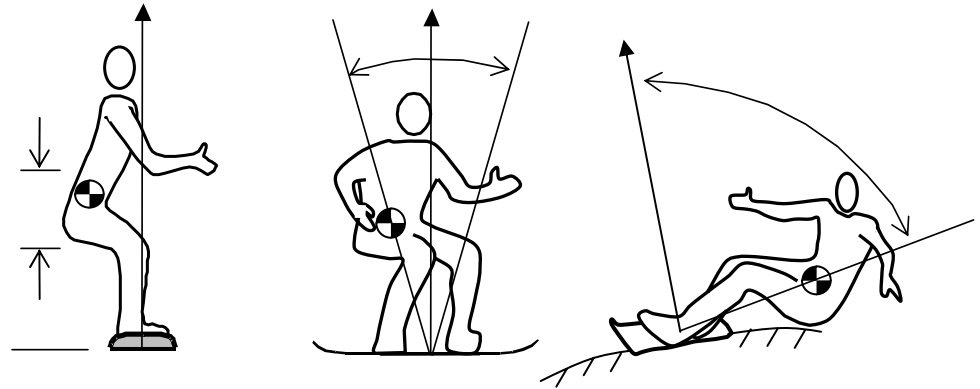
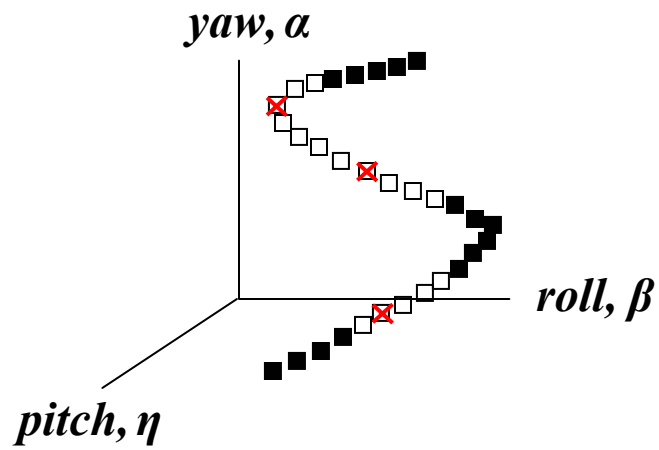
Repeat for different values of yaw



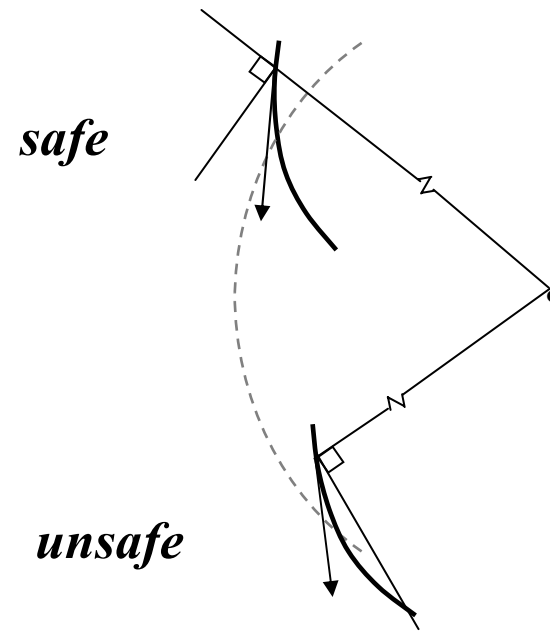
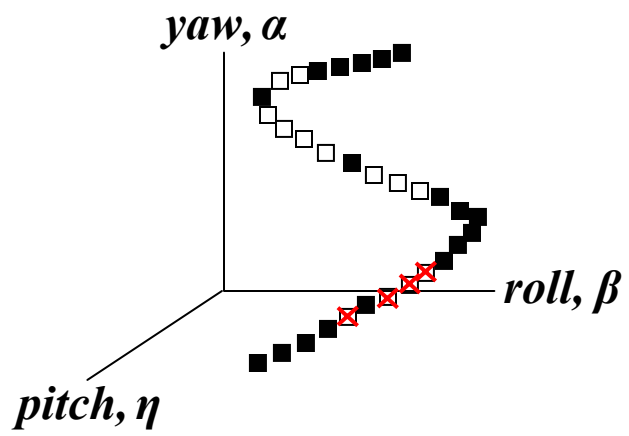
# Skill Level: Roll, Yaw



# Skill Level: cg Position

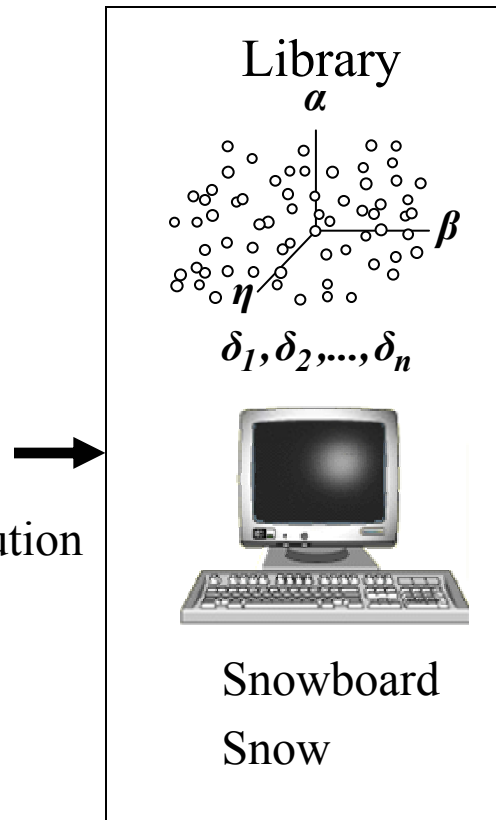


# Safely with Ease



# Use of the Library

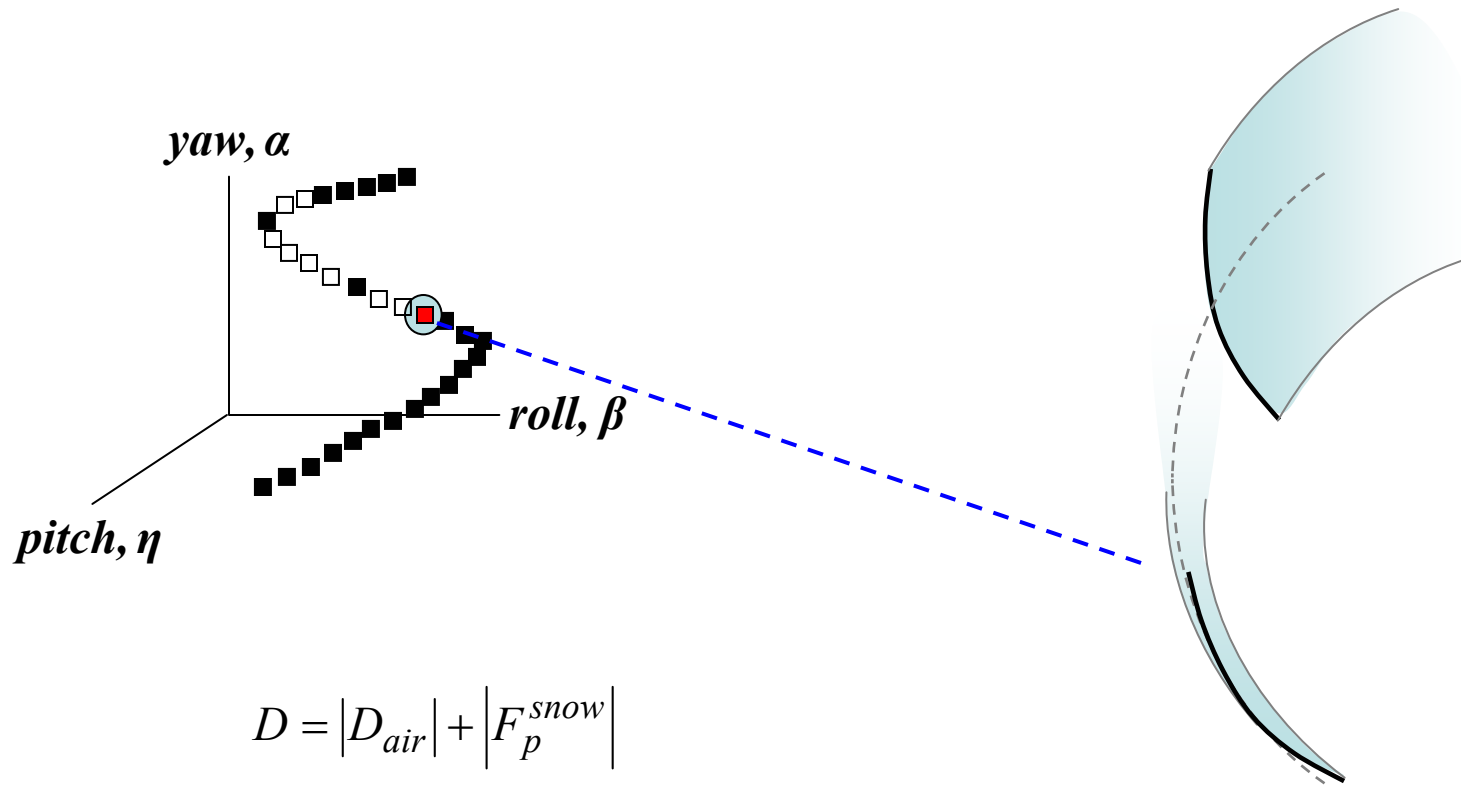
- ◆ Snowboarder
  - ◆ Weight
  - ◆ Height
  - ◆ Skill level
  - ◆ Weight Distribution
- ◆ Slope
- ◆ Radii
- ◆ Entering Speed



- ◆ Highest speed
- Within skill level
- Safely with ease
- ◆ Total Time



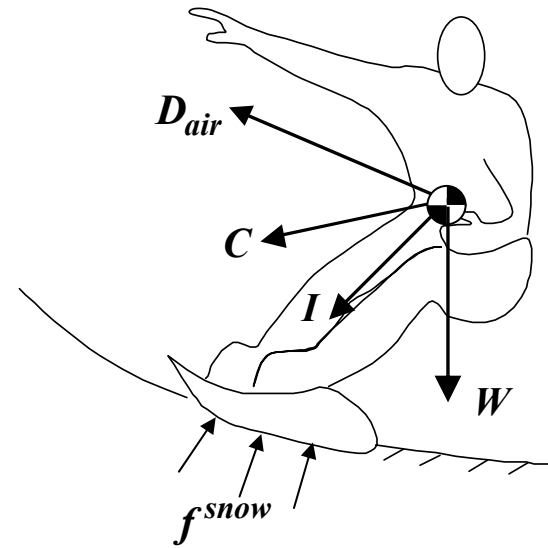
# Minimum Drag



$$D = |D_{air}| + |F_p^{snow}|$$

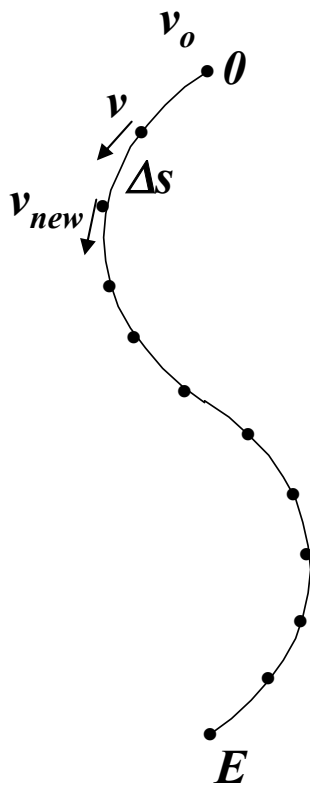
Select “point” with smallest yaw

# Time to Complete the Course



Time  $\longrightarrow \Sigma F = m \frac{dv}{dt}$

# Time to Complete Course



$$a_p = \frac{W_p + I_p - D}{m}$$

$$\Delta t = \frac{\Delta s}{v}$$

$$v_{new} = v + a\Delta t \longrightarrow \text{Check } v_{new} \stackrel{?}{\leq} v_{\max}$$

$$t_e = \sum \Delta t$$

# Virtual Tests

~~Build  
Prototypes~~



~~Laboratory  
Tests~~



~~On-Snow  
Tests~~



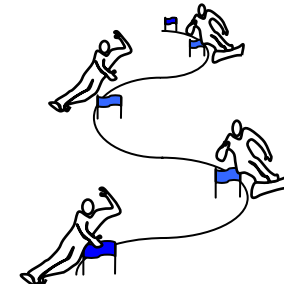
Simulation



- ◆ Bending stiffness
- ◆ Torsional stiffness
- ◆ Flex
- ◆ Twist



Simulation

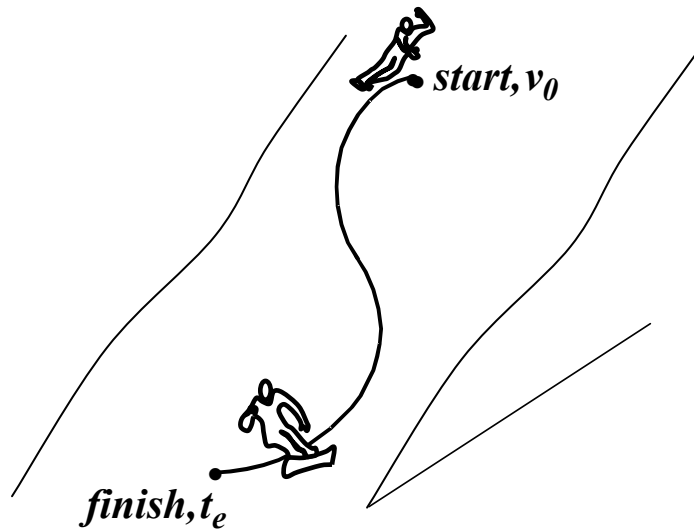


- ◆ Time

# Verification: On-snow Tests

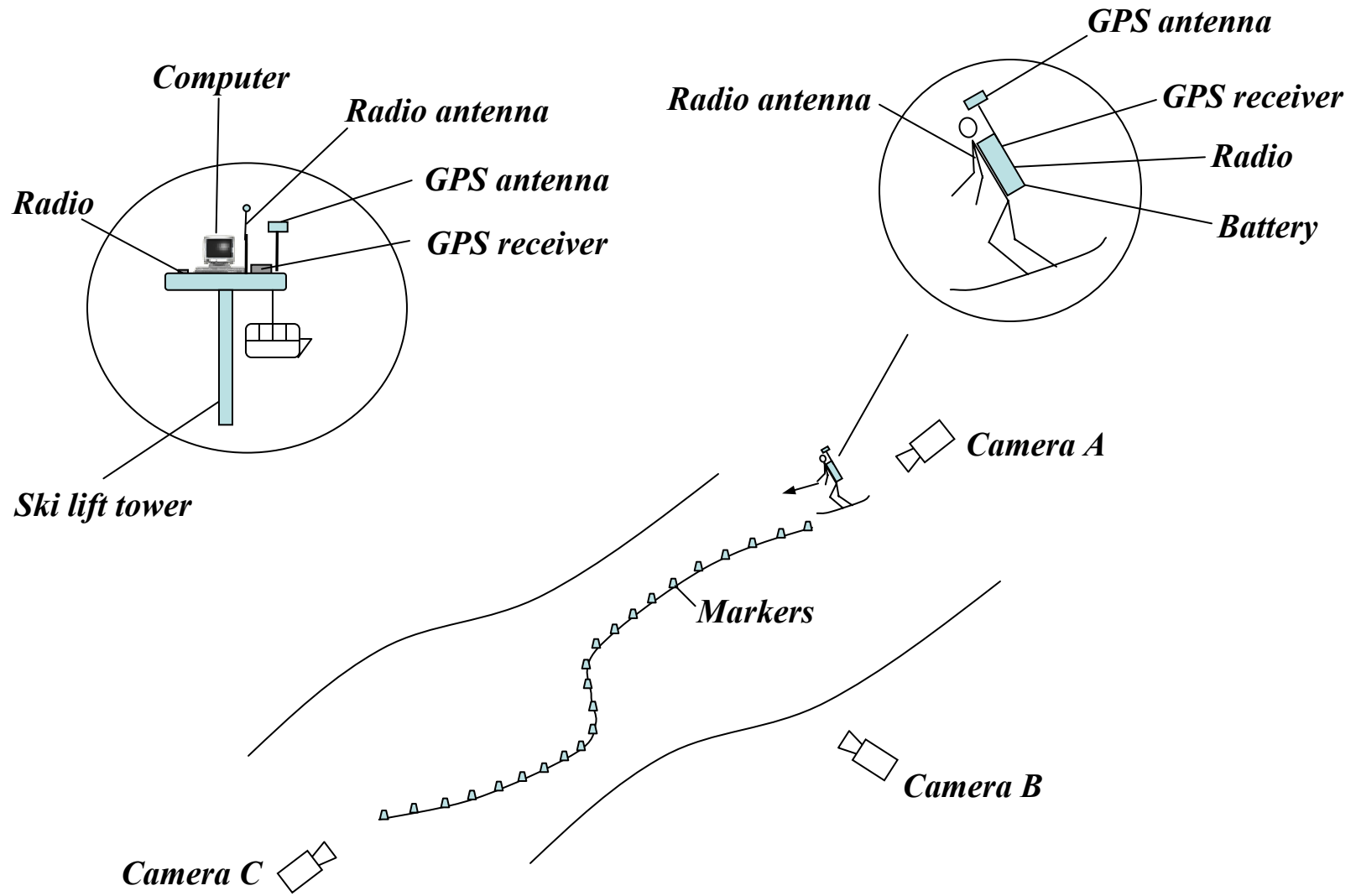
K2 Spitfire 164

K2 Astar 147

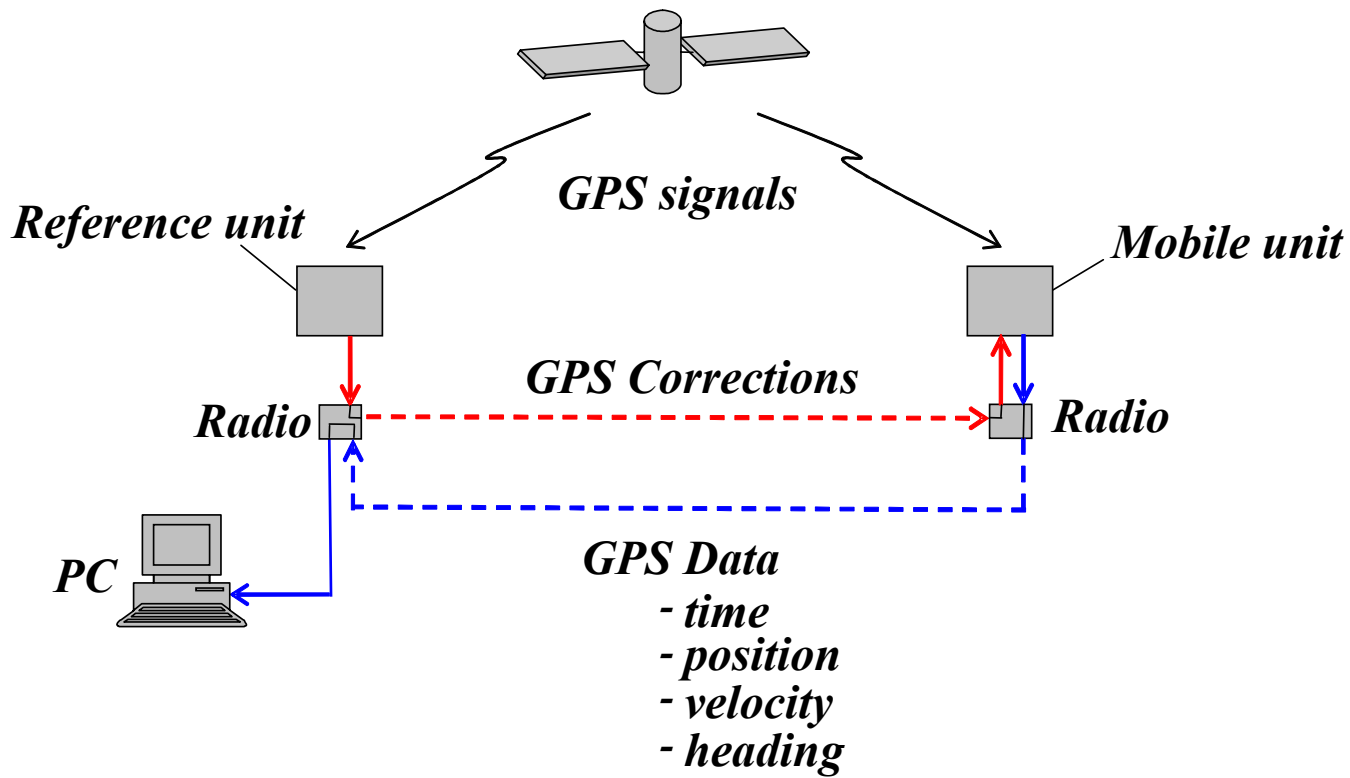


- ♦ Time to complete course
- ♦ Speed
- ♦ Roll angle

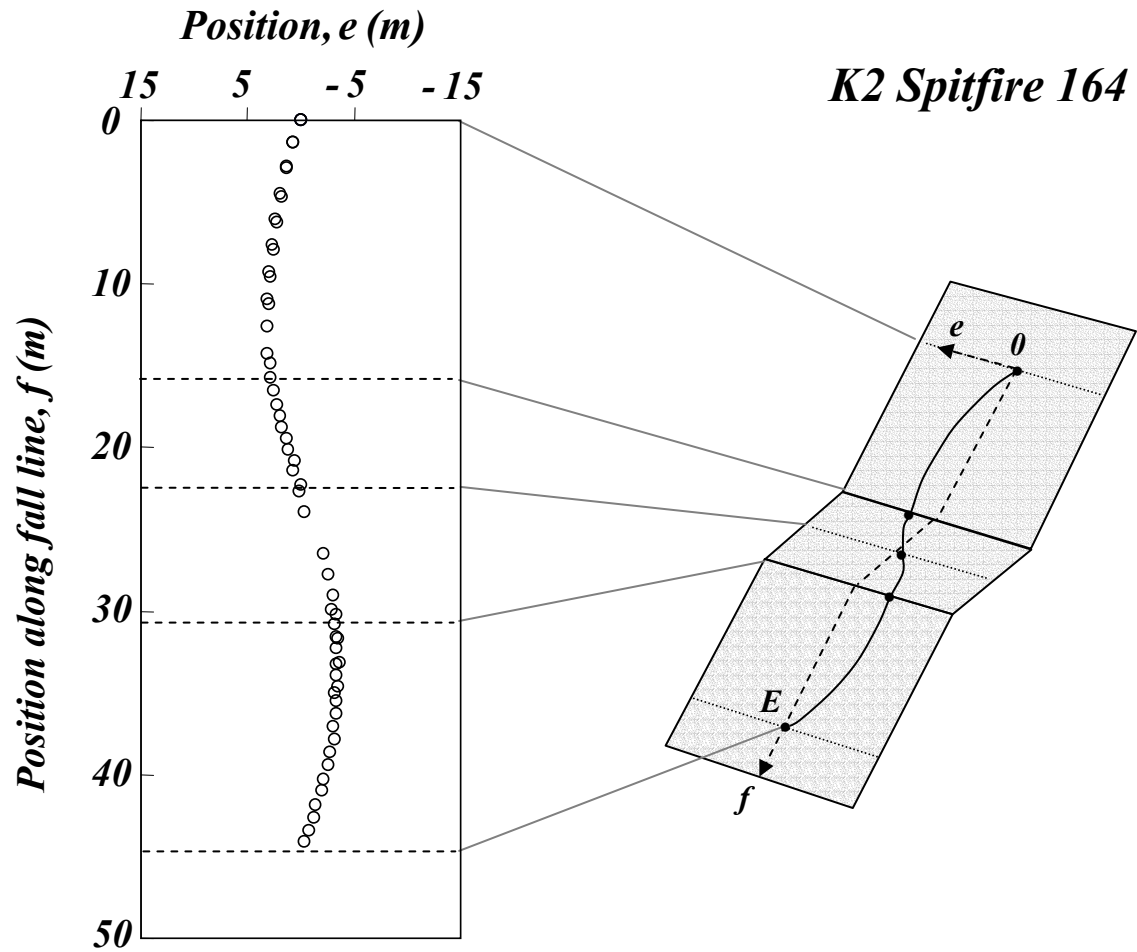
# On-snow Verification: Test Setup



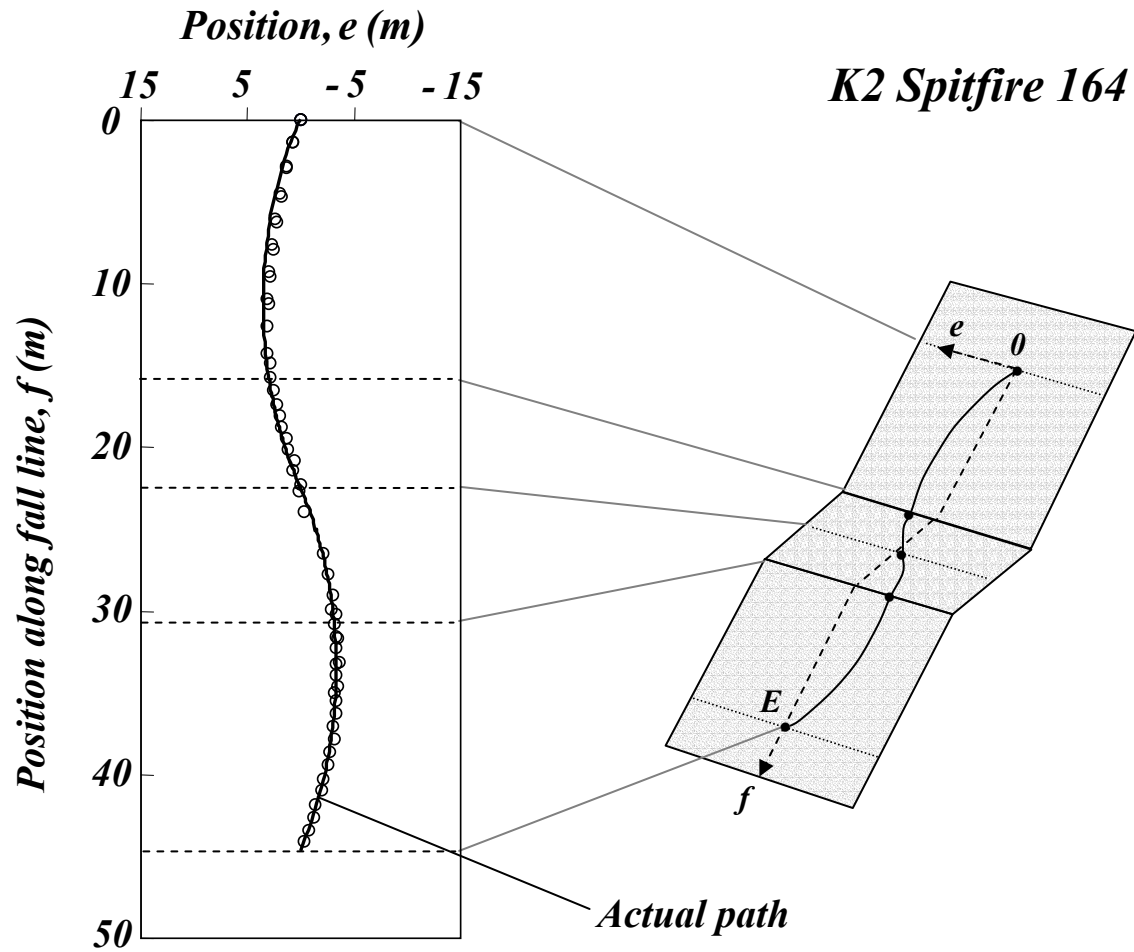
# The GPS System



# GPS Position Data



# GPS Position Data



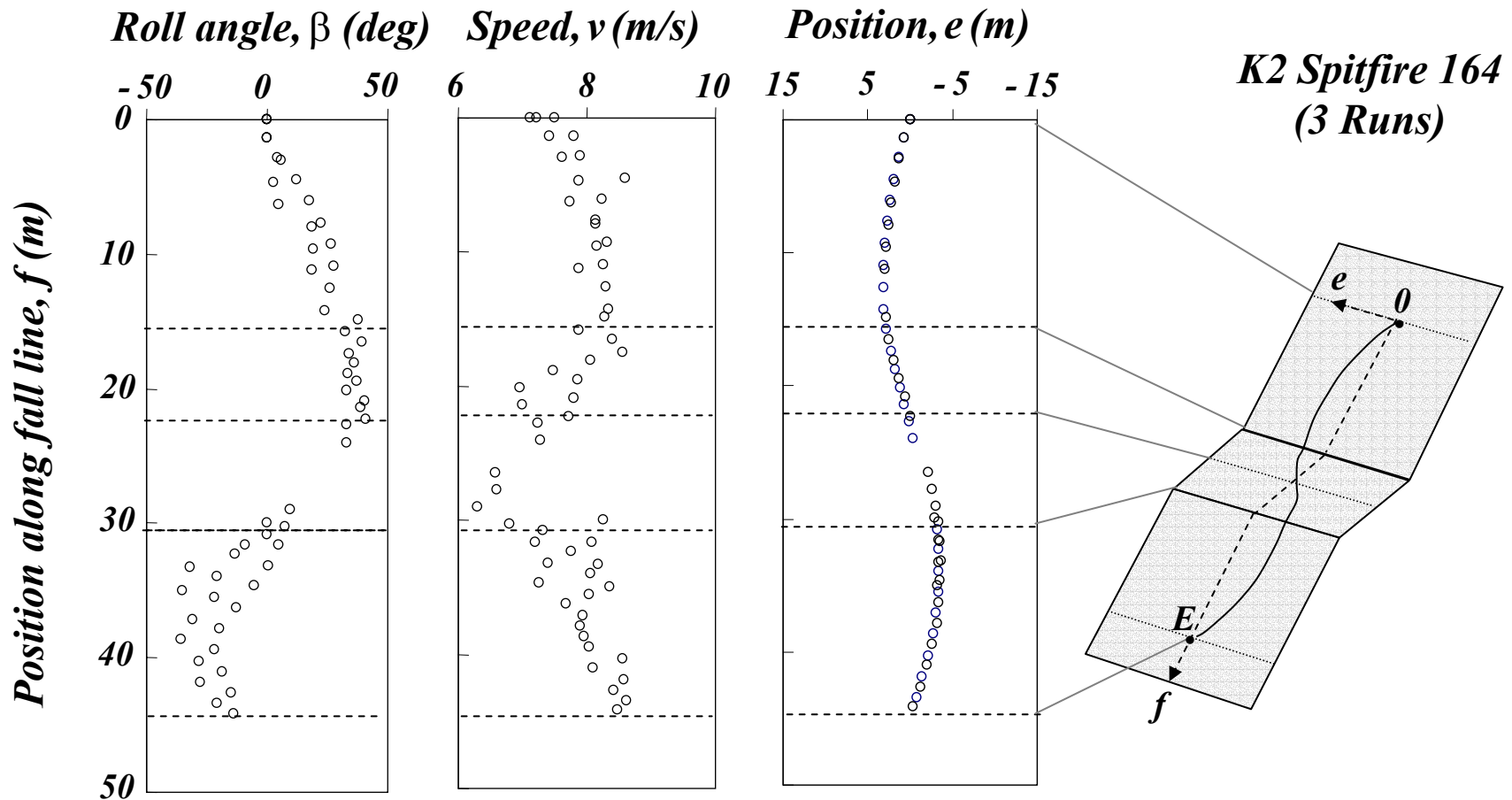
# On-snow Verification: Roll Angle



# On-snow Verification: Roll Angle



# On-snow Verification: Data



# On-Snow Verification: Model Inputs

## ◆ Snowboard

Geometry

Properties (stiffnesses along length)

## ◆ Snowboarder

Weight (with GPS): 712 N (160 lbs)

Height: 1.63 m

$-60 < \text{roll} < 60$  deg

$-30 < \text{yaw} < 30$  deg

$\Delta h_{\text{max}} = 0.25$

$-15 < \zeta_{\text{cg}} < 15$  deg

$-40 < \kappa_{\text{cg}} < 40$  deg

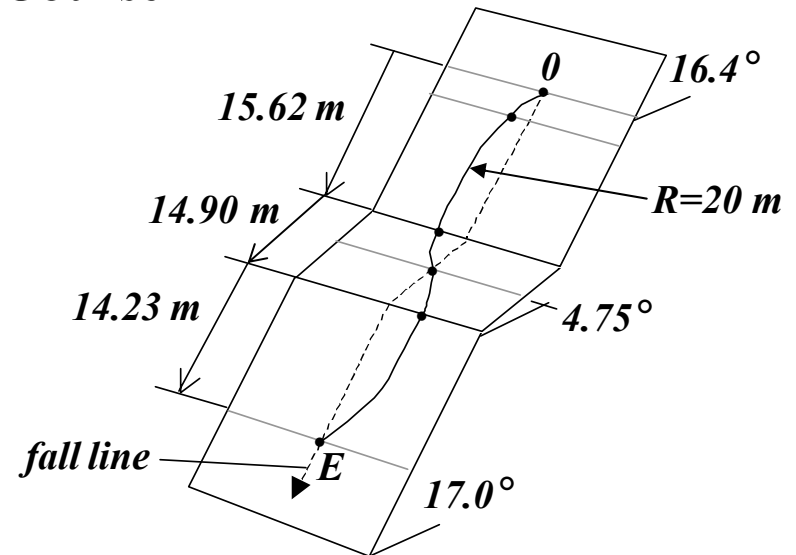
$\frac{W^f}{W^b} = 1.5$

## ◆ Entering Speed

7.3 m/s K2 Spitfire 164

5.4 m/s K2 Astar 147

## ◆ Course



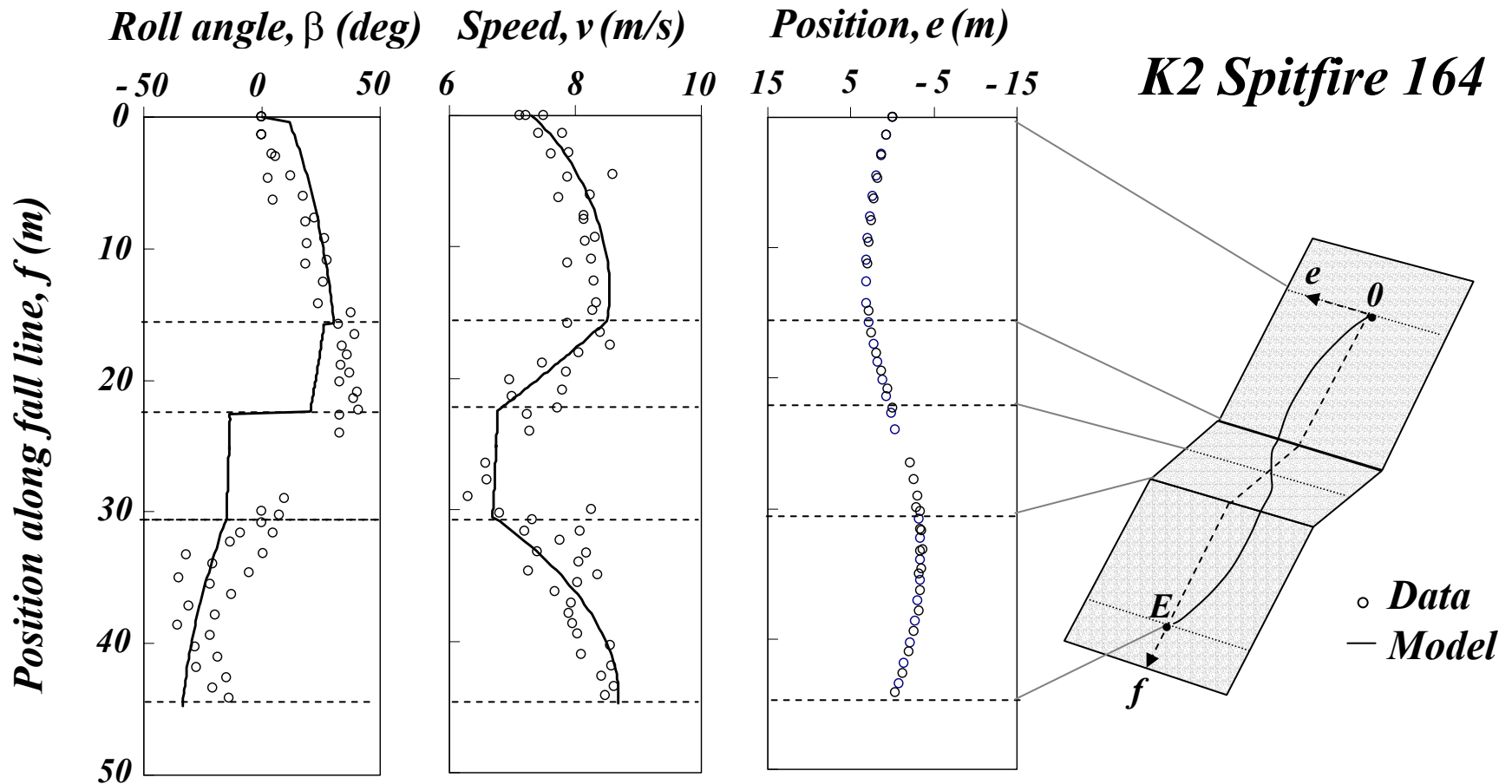
Snow:  $K_{\text{sn}}=20\text{e}6$  Pa,  $\tau=15\text{e}3$  Pa

Air density:  $1.2$  kg/m<sup>3</sup>

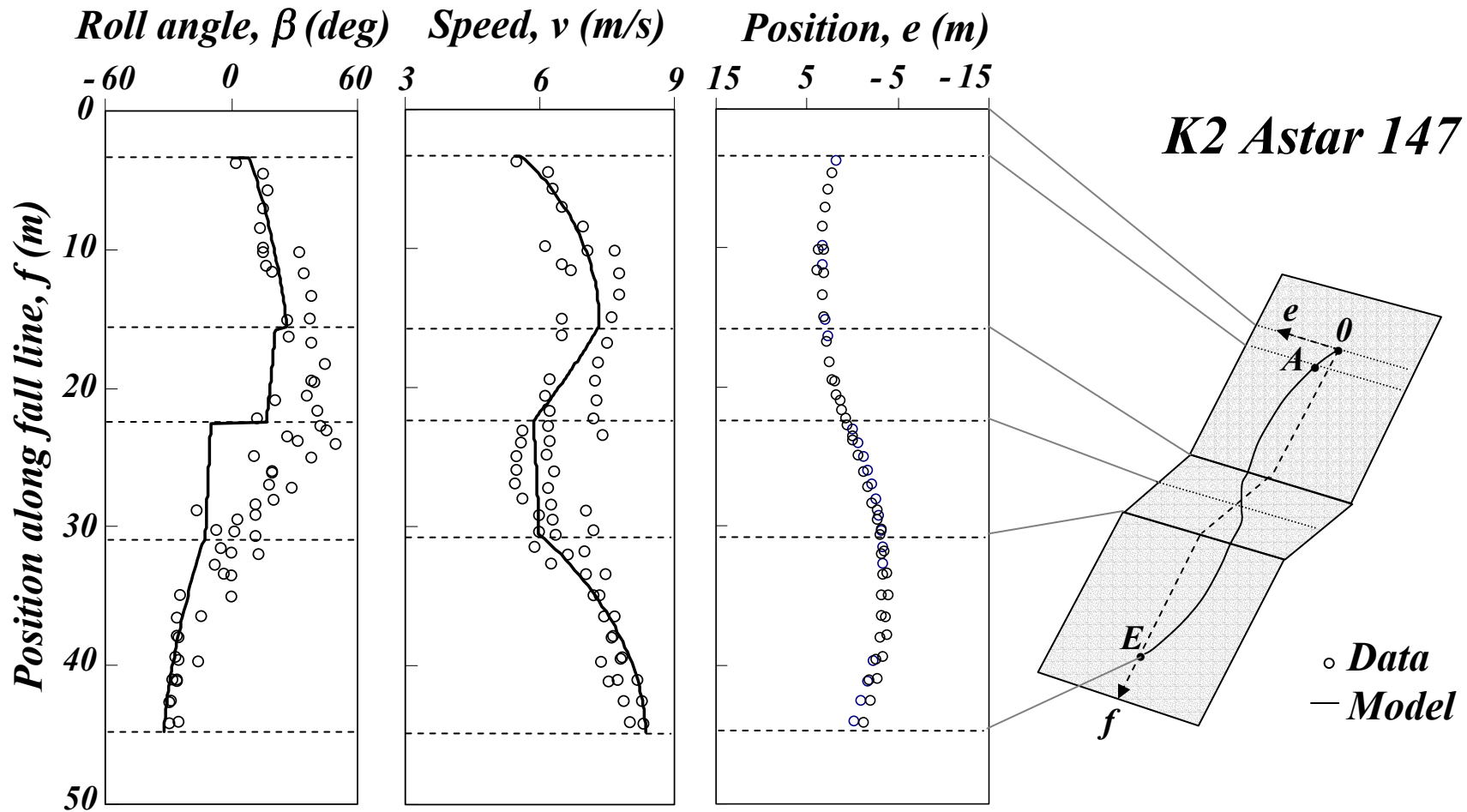
Frontal Area:  $0.4$  m<sup>2</sup>

Drag coefficient:  $0.5$

# On-snow Verification: Results



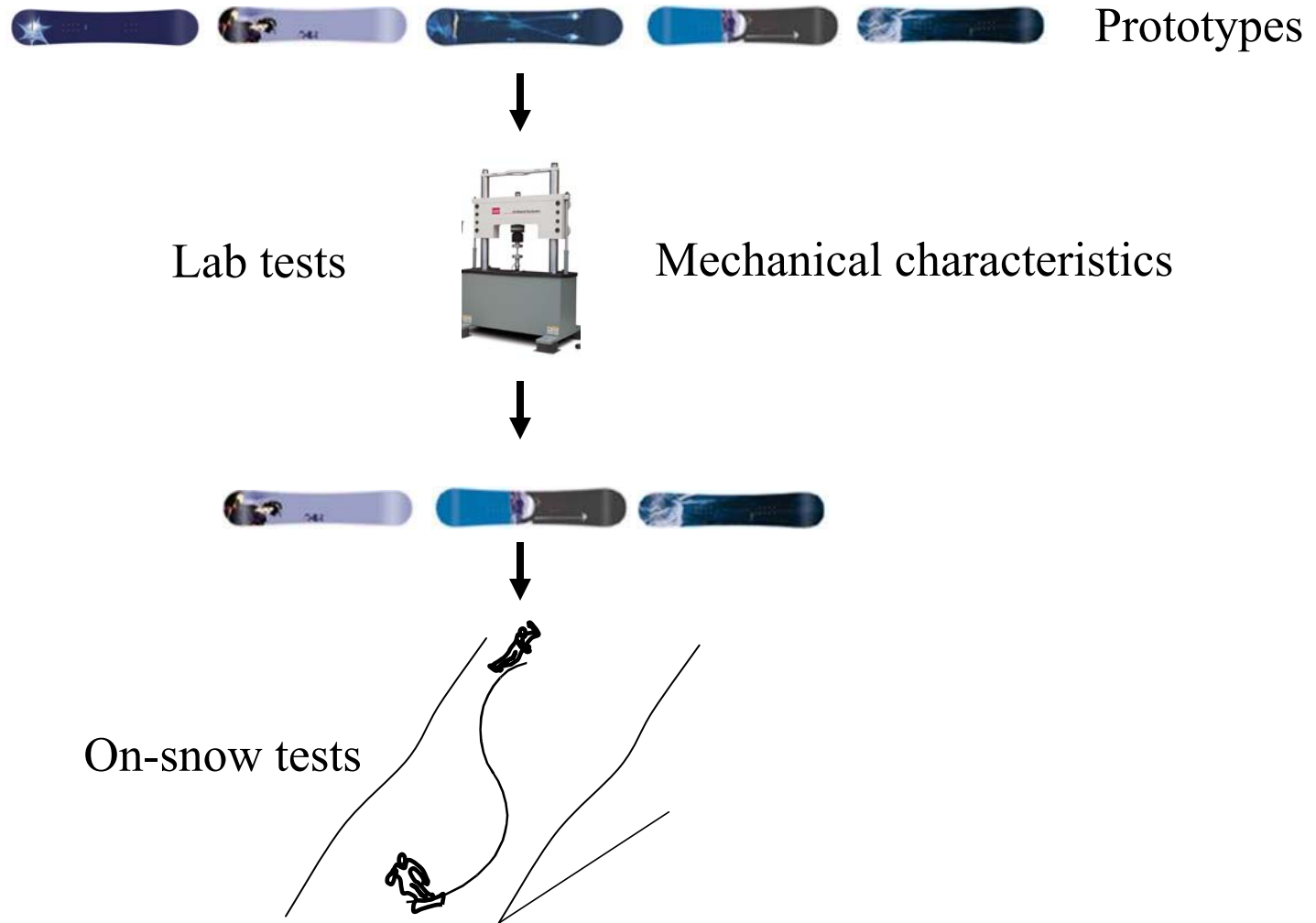
# On-Snow Verification: Results



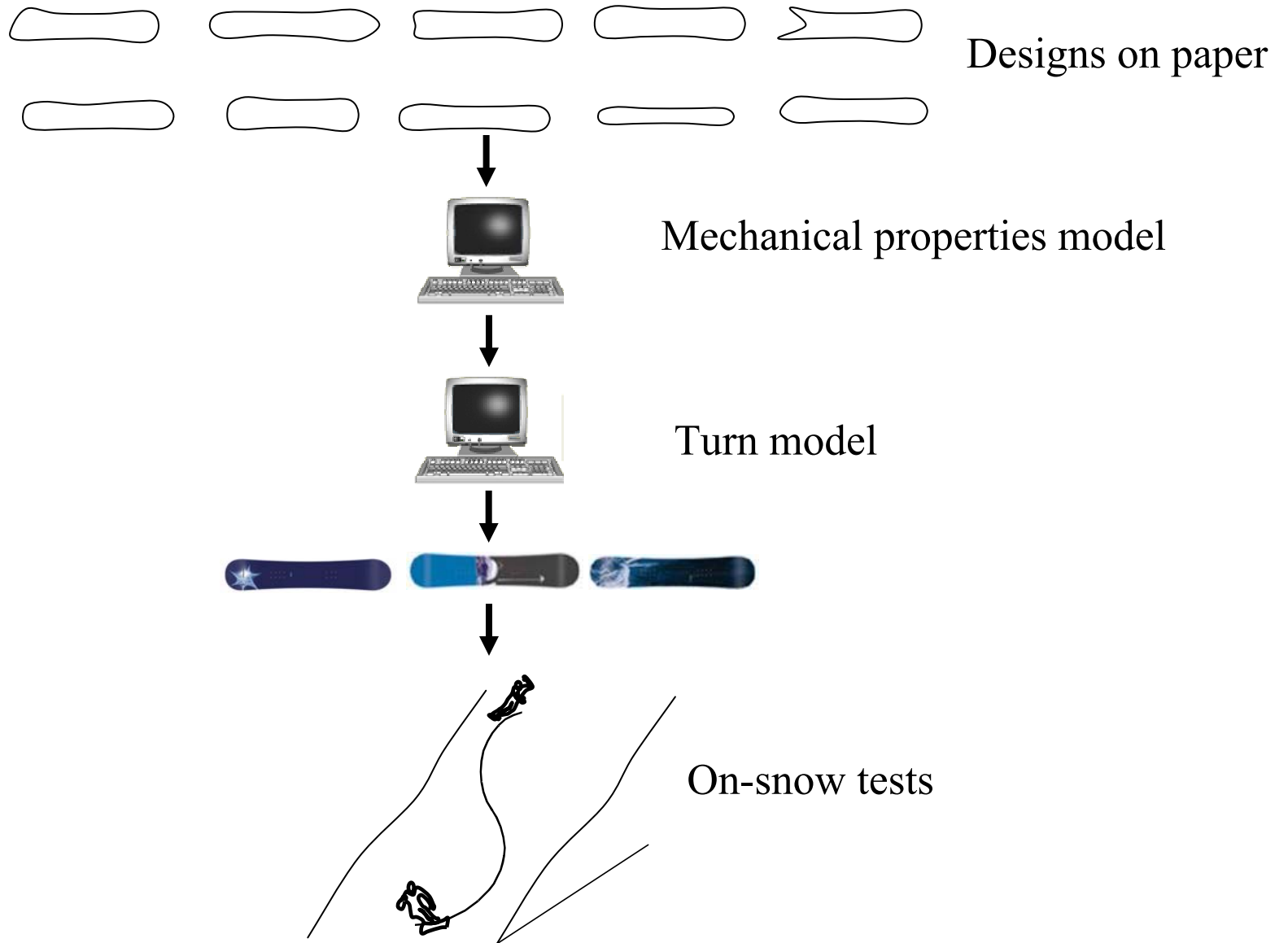
# Time to Complete Course

	K2 Astar		K2 Spitfire	
	Time	Difference (model vs. data)	Time	Difference (model vs. data)
Model	6.44 s	---	6.07 s	---
Run 1	7.23 s	12.3%	6.00 s	1.1%
Run 2	6.67 s	3.4%	5.87 s	3.3%
Run 3	7.06 s	9.6%	5.26 s	13.3%
	Spread in data: 5.8%		Spread in data: 14.0%	

# Summary: Design Process-Present



# Summary: The Design Process



# The Possibilities

- ◆ Snowboarder
- ◆ Snowboard
- ◆ Course



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- ◆ My family

# Snow Force

