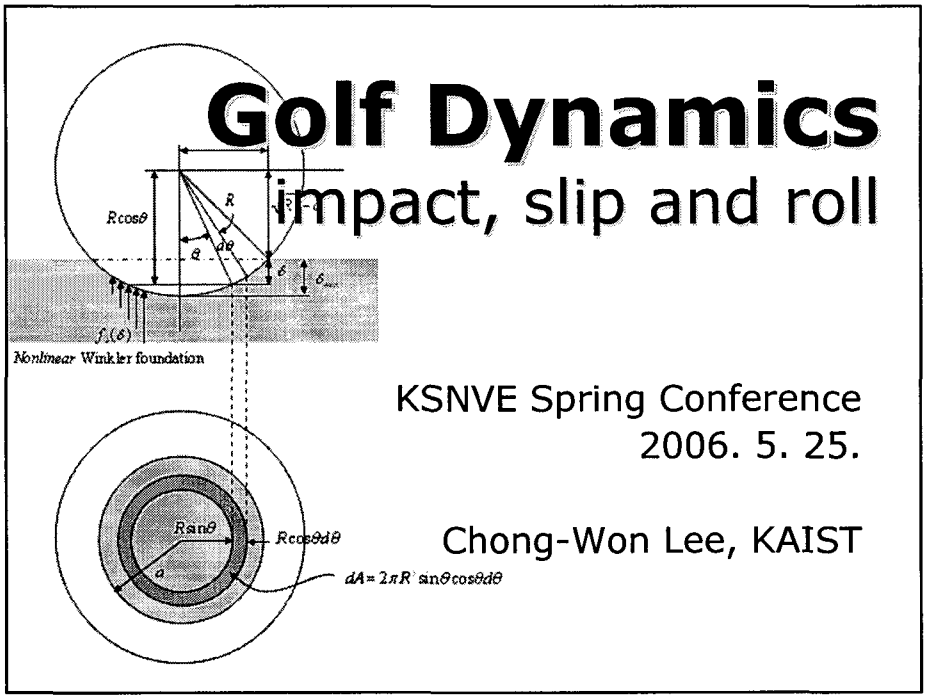
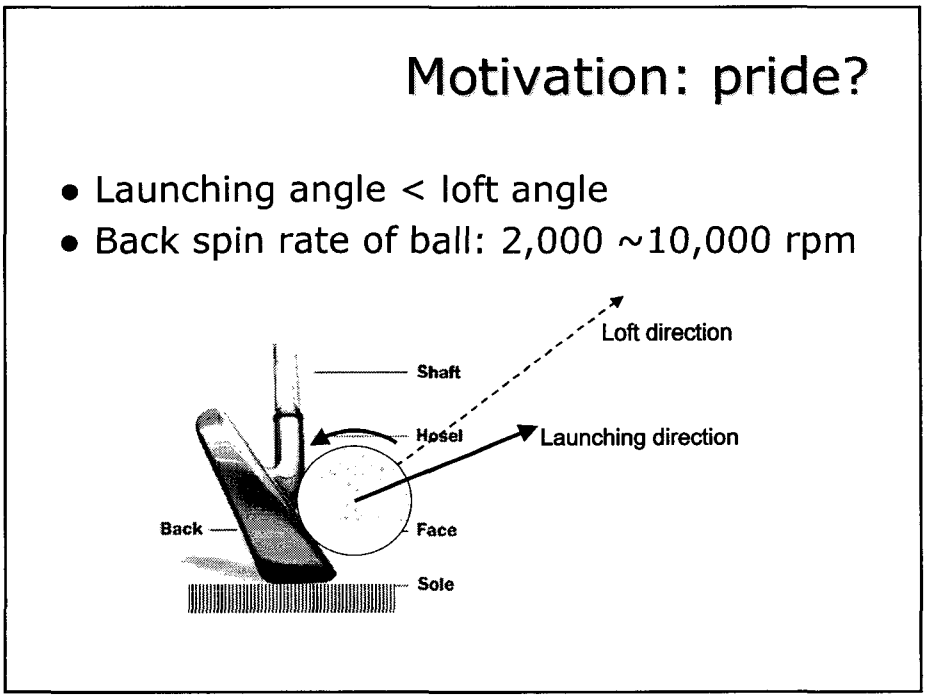
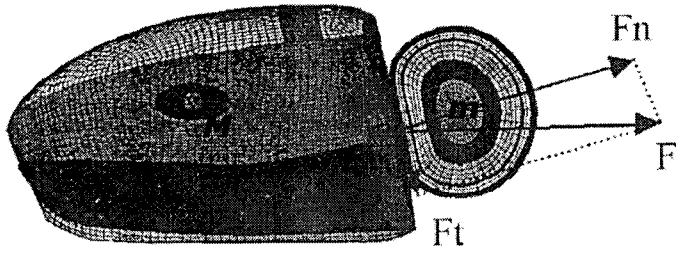

Golf Dynamics
impact, slip and roll
Rcosθ
R
δ
δmax
Nonlinear Winkler foundation
KSNVE Spring Conference
2006. 5. 25.
Chong-Won Lee, KAIST
Rsinθ
Rcosθdθ
dA= 2πR² sinθcosθdθ

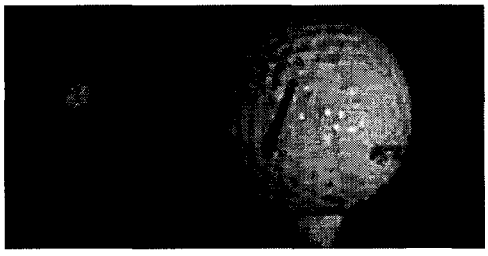

Motivation: pride?
• Launching angle < loft angle
• Back spin rate of ball: 2,000 ~10,000 rpm
Loft direction
Shaft
Hosel
Launching direction
Back
Face
Sole

Presentation

- Fundamentals of dynamics
  - 뿃 lip-roll of ***rigid/deformable*** sphere.
- Impact dynamics
  - 뿃 henomenon: impact of ***deformable*** sphere against ***rigid*** target
  - 뿂 all launching angle > club loft angle?
  - 뿃 layers with high club head speed need low lofted drivers?
- Green dynamics
  - 뿃 timpmeter?
  - 뿊 hat stops ball on the green?
  - 뿃 utting dynamics: dynamics of ***rigid*** sphere on a ***deformable*** foundation

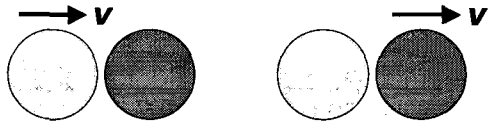
Impact of ball-club



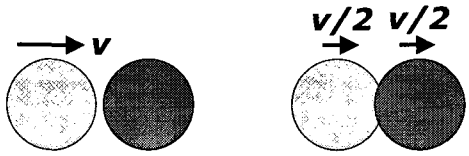


Impact of two balls

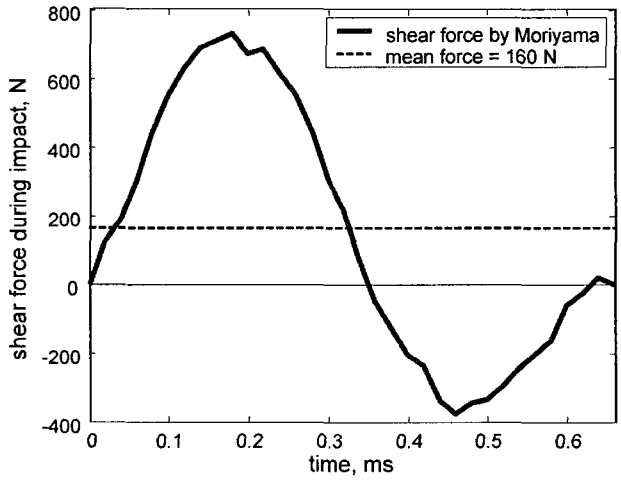
- Perfect elastic (rigid) contact: momentum & energy are conserved.



- Perfect plastic contact: momentum is conserved, but energy is reduced to half.



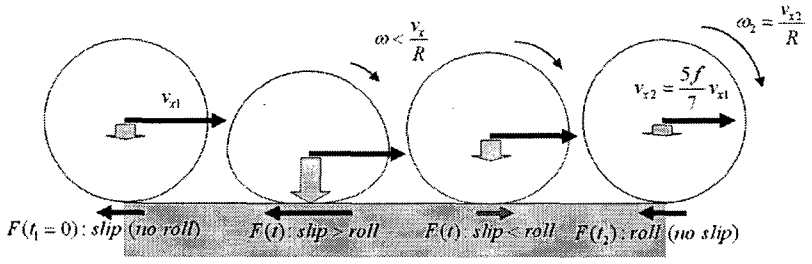
Shear force during impact



Moriyama, et al. (2004)

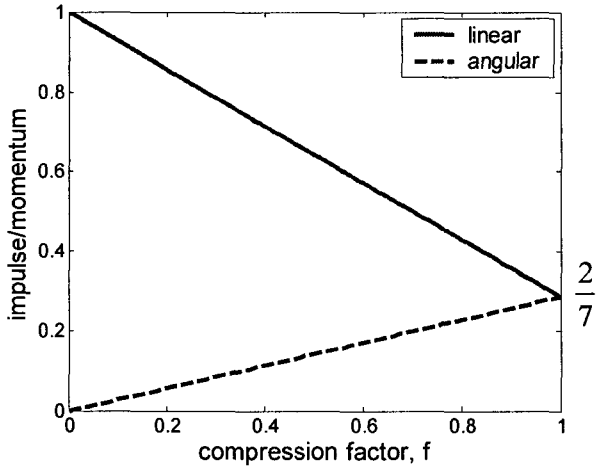
Slip/slide of ball

- Linear impulse-momentum eq.
- Torque impulse-angular momentum eq.
- *f* (compression factor) = 1 for rigid ball



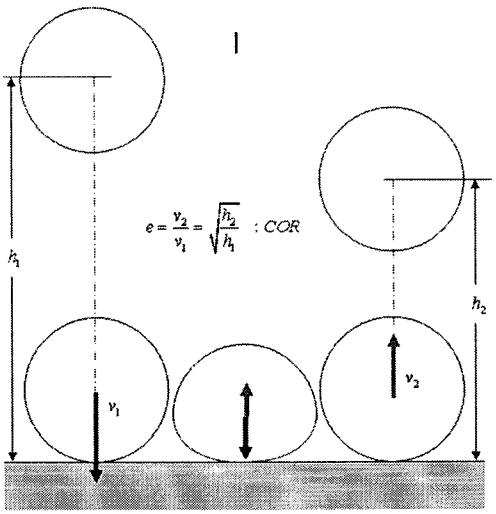
Impulse vs compression

- w/o knowledge of shear force history



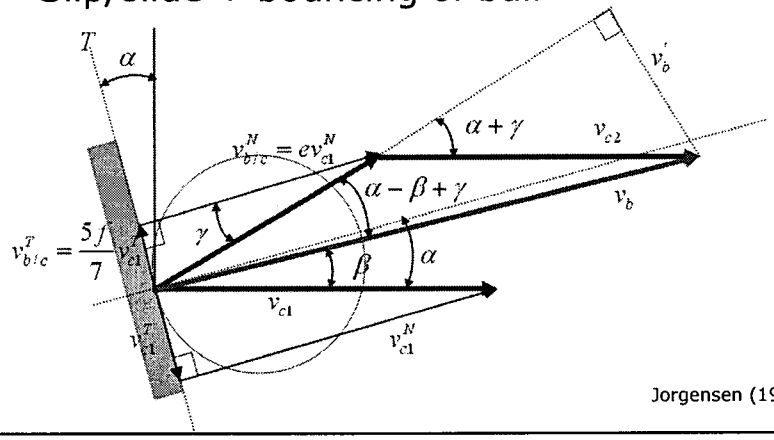
Bouncing of ball

- COR



Impact of ball-club

- Linear momentum conservation along swing path: club+ball
- Slip/slide + bouncing of ball



Jorgensen (1999)

Impact of driver

- Loft angle = 8~12.5 degrees
- Club head speed = 30~60 m/s
- Ball speed = 45~90 m/s
- Impact duration = 0.5~0.65 ms
- Linear impulse > ~0.1 N-sec
- Torque impulse = ~0.002 N-m-sec
- Slip distance = 2 (hard)~3 (soft) mm
- Natural frequencies of club head and ball = ~ 1000 Hz
- Back spin rate?

Ball launching angle

$$\tan\beta = \frac{e(1+a)\left\{1+\left(\frac{5f}{7e}\right)\right\}\tan\alpha}{(1+e)+\left\{1-\left(\frac{5f}{7}\right)\right\}\tan^2\alpha} < \tan\alpha \quad ??$$

- Sufficient condition for all e, f :

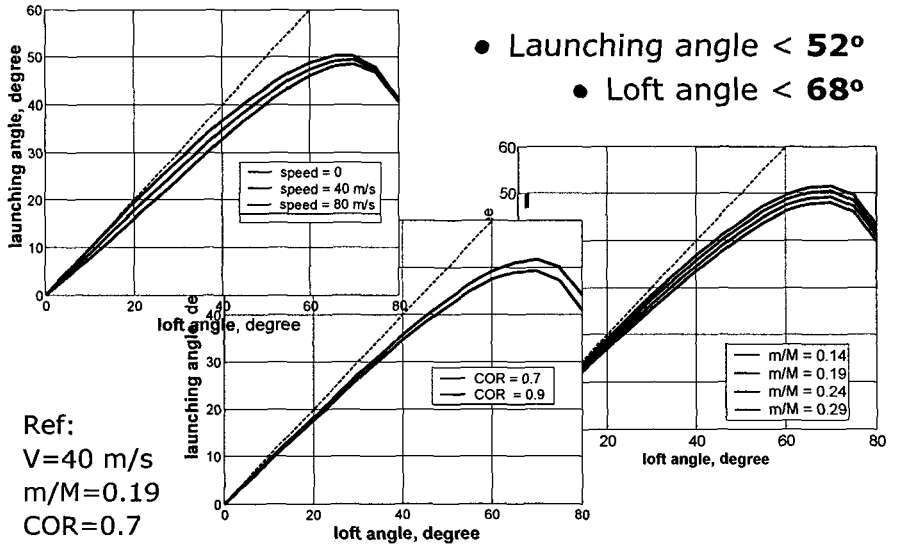
$$a = \frac{m\ (\text{ball mass})}{M(\text{club mass})} < \frac{1}{6}$$

빽 SGA rule: m < 45.93 *gr*

뺐 t holds for M > 275.6 *gr*

– *Driver is the lightest club > 280 gr (women)*

Ball launching angle

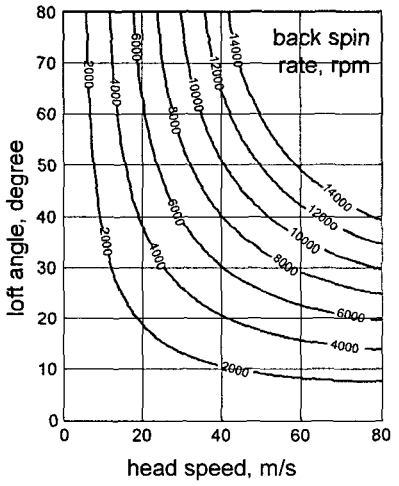


- Launching angle < **52°**
- Loft angle < **68°**

Ref:
V=40 m/s
m/M=0.19
COR=0.7

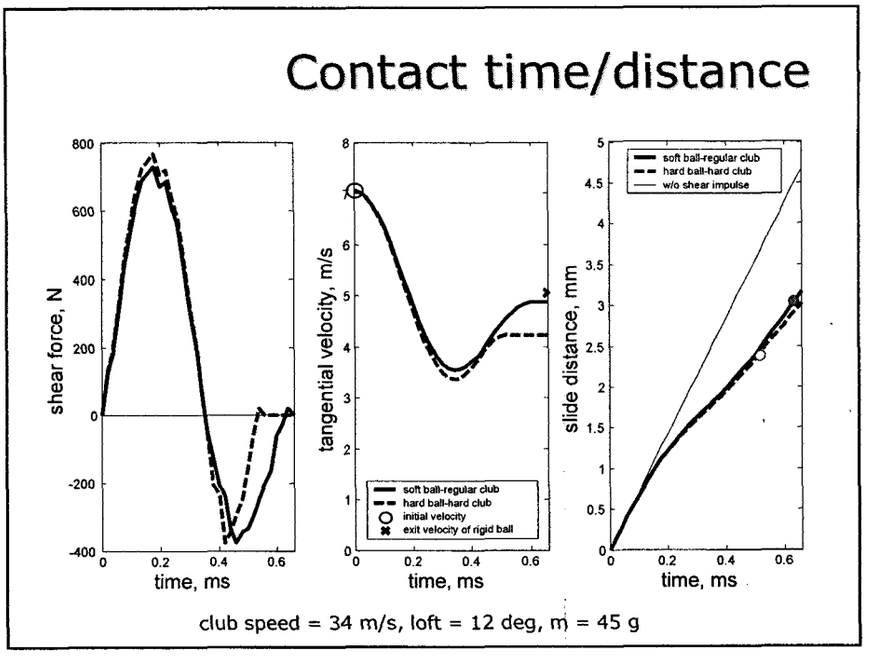
Ball back spin rate

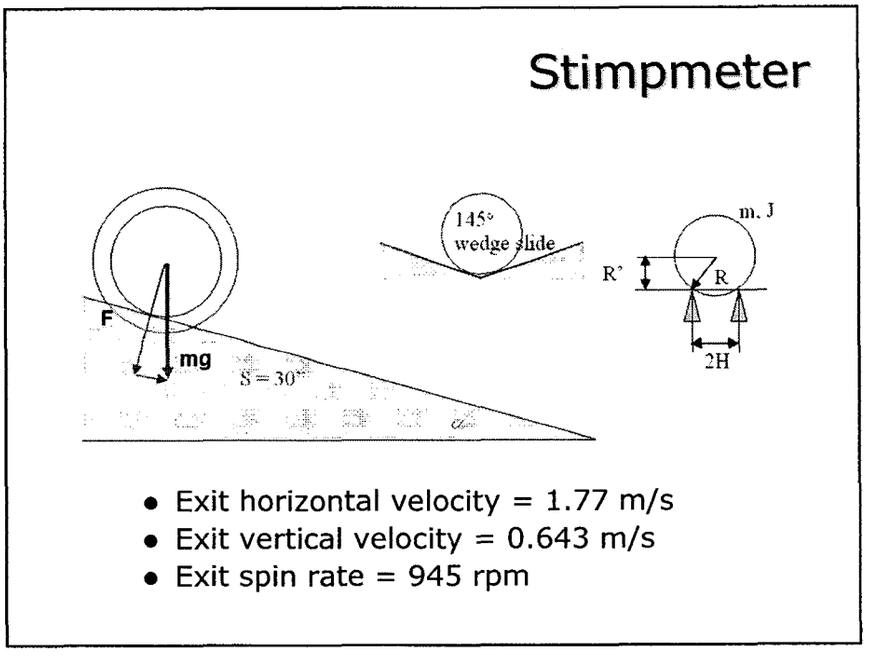
$$\omega_b = \frac{v_{b/c}^T}{R} = \begin{cases} \left(\frac{5f}{7}\right)\frac{v_{c1}\sin\alpha}{R} \\ \frac{1}{R}\left(v_{c1}\sin\alpha - \frac{\int F(t)dt}{m}\right) \end{cases}$$



- Lee뭘 rule of thumb:

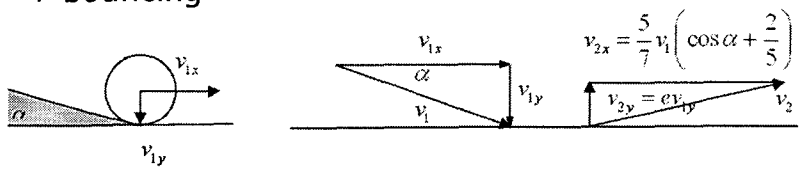
Spin (rpm) = [2 x loft (degree)] x club speed (mph)


Contact time/distance
shear force, N
time, ms
tangential velocity, m/s
soft ball-regular club
hard ball-hard club
initial velocity
exit velocity of rigid ball
time, ms
slide distance, mm
soft ball-regular club
hard ball-hard club
w/o shear impulse
time, ms
club speed = 34 m/s, loft = 12 deg, m = 45 g

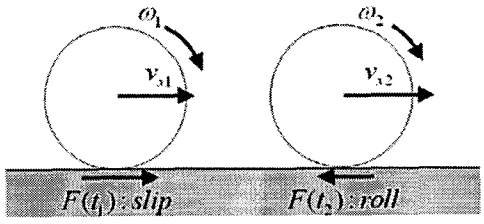

Stimpmeter
F
mg
S = 30°
145°
wedge slide
m, J
R'
R
2H
• Exit horizontal velocity = 1.77 m/s
• Exit vertical velocity = 0.643 m/s
• Exit spin rate = 945 rpm

Rolling of ball on putting green

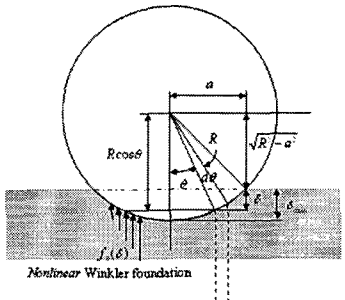
- Linear/torque impulse-linear/angular momentum + bouncing

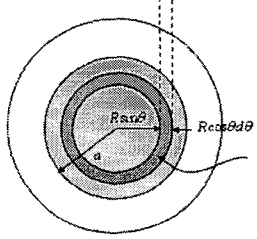


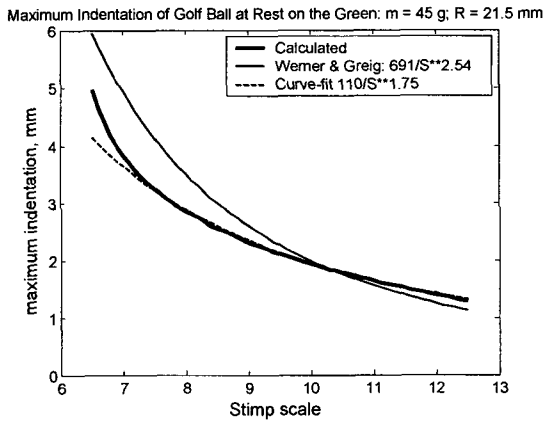
- Roll spin = 850 rpm, roll velocity = 1.83 m/s
- Slip distance = 1.5 cm



Max sag of ball on green

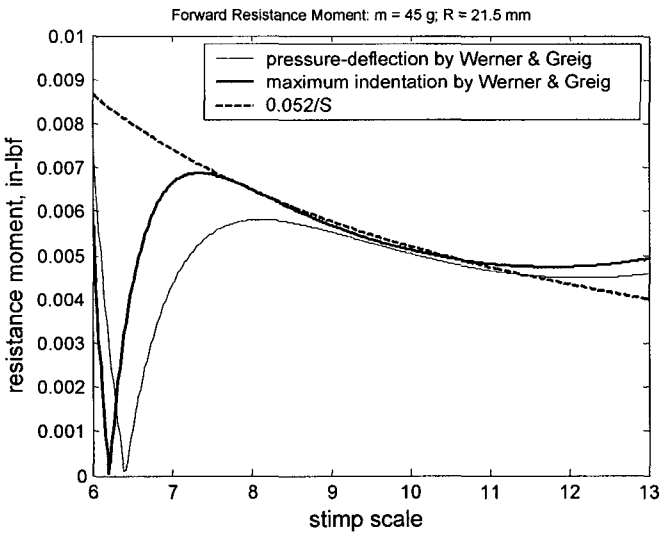




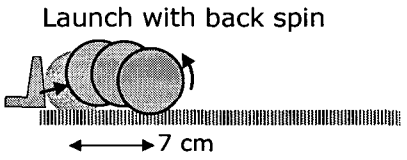


- Empirical nonlinear stiffness of green by Werner & Greig

Rolling resistance moment



Putting dynamics: 3 *m* putt



- One stimpmeter putt of 9
- Fly~(4-2)mm
- Launching angle ~3.2/4°
- Back spin~60 rpm
- Skid friction coeff ~ 0.8