The Physics of Breaking in Taekwondo

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Rev. A

Physics

- Mass
- Velocity
- Acceleration
- Force
- Energy
- Elastic Modulus

Mass

A measure of a bodies resistance to acceleration. When the acceleration is gravity, the resulting force is the body's "weight".

$$M=F/a$$

Take-away: The weapon has a mass, and the target has a mass.

Units of measure: grams, kilograms

Velocity

The rate of change of its position with respect to a frame of reference, and is a function of time.

$$V=x/t$$

Take-away: The velocity of a projectile “weapon” (fist, foot) can be more important that any other property.

Units of measure: MPH, meters per second

Acceleration

The rate of change of a body's velocity as a function of time.

$$a=v/t$$

Take-away: The "deceleration" of a projectile "weapon" (fist, foot) at the target determines the force that can be applied.

Units of measure: G

"On earth, the acceleration due to gravity is about 10 meters per second per second."

Force

Any interaction that, when unopposed, will change the motion of an object.

$$F=ma$$

Take-away: The force applied to a “target” is equal to the mass of the “projectile weapon” times the rate it’s velocity changes (acceleration or “deceleration”).

Units of measure: newton, pound, dyne

“One newton is about the force exerted by the weight of an apple.”

Energy

In physics, energy is the quantitative property that must be transferred to an object in order to perform work on, or to heat, the object.

$$E = \frac{1}{2} m v^2$$

$$E = \text{Force} \times \text{Deflection}$$

Take-away: If you cannot control the mass of an object, the only way to change its energy is by changing its velocity. Doubling the velocity of a mass increases it's energy by a factor of FOUR.

Units of measure: Joule, erg, calorie, BTU, watt-hours

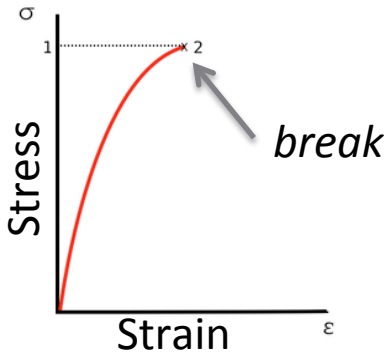
"There are about 100 joules of energy available in a hand strike."

Elastic Modulus

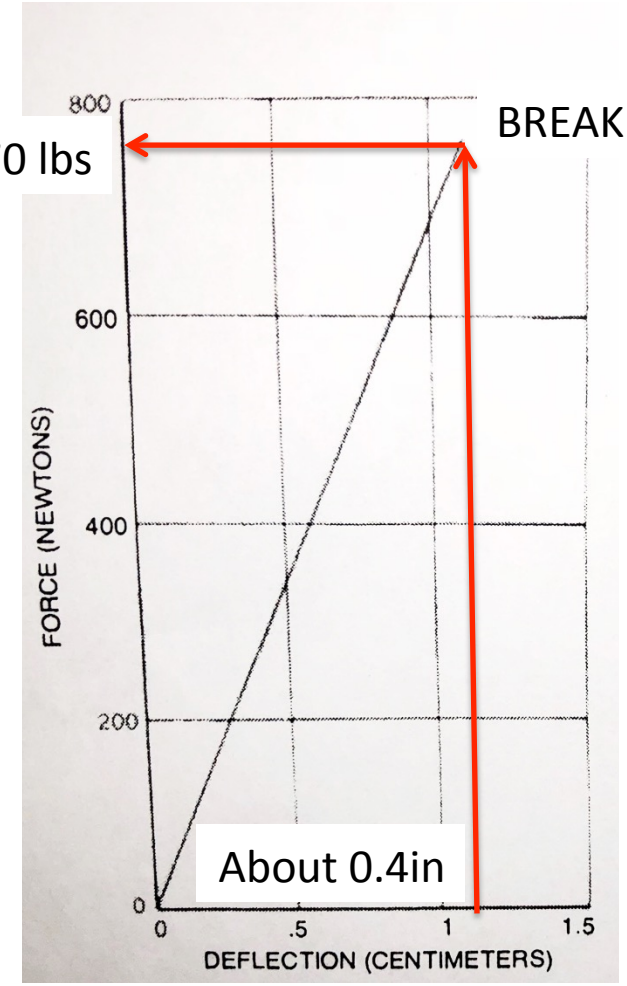
Modulus of Elasticity measures an object's resistance to being deformed elastically (i.e., non-permanently) when a stress is applied to it.

Modulus= stress / strain

Take-away: To break a board, you need to apply a critical force. When the Modulus is low, the board will bend long before it breaks (wet wood, plastic). When the Modulus is high, the board will snap with little bending (dry wood, glass).



Elastic Modulus of Wood



Some Facts...

- A wood board will **deflect about a centimeter** before breaking.
- “The hand needs about 12 joules of energy to break wood.”
- “There are about 100 joules of energy available in a [hand] strike.”
- “The hand needs to reach a speed of about 18 FPS to break wood.”

Lost energy

- Not all of the energy put into a hand or foot by accelerating it will be delivered to the “break”.
- Deformation of the hand or foot uses energy.
- Motion of the holders uses energy.
- Low-modulus targets, like wet wood, use more energy.

A surprising discovery...

"... The interaction process is closer to inelastic than elastic, with **the effective striking mass being that of the fist alone**, as anticipated. Elastic collisions are ruled out by the high-speed movies, which show that the fist and block are in contact for several milliseconds, and thus appear to stick together."

Nope.

EQUALS

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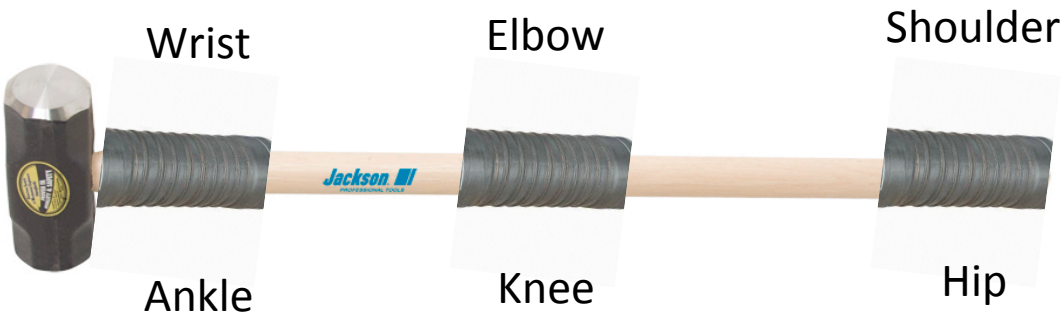
Closer.

Rubber couplings.....



UNITED TAE KWON DO
KOREAN MARTIAL ART

The board is broken before the body can contribute energy to the break.

The job of the body is acceleration to maximum velocity and configuring the hand or foot for maximum energy transfer.

References

- The Physics of Karate, Feld, McNair and Wilk, Scientific American, 1979, pp 150-158.
- The Physics of Karate, Wilk, McNair, American Journal of Physics, Volume 51, Issue 9, September 1983, pp 783-790.
- Steven Wilk, personal communications.

PART 2

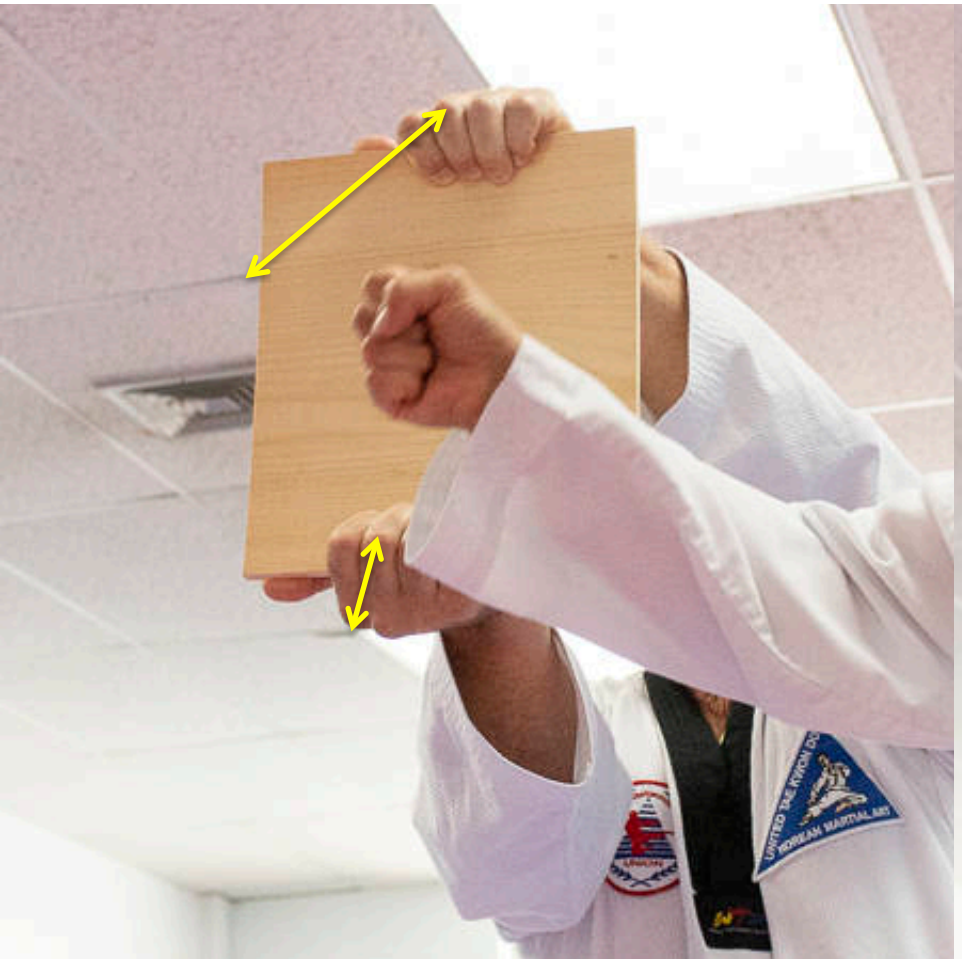
Case Studies

- These photographs were taken at the UTKD/ UKMA Black Belt Test on June 9th, 2018, in Pelham NH.
- Unless otherwise noted, successive frames were shot at 12 FPS, or 83 mS between exposures.
- No calibration was performed at the time of the event, so consider the number as approximate.
- The boards are 12-inches across the grain, 10-inches with the grain, dry pine.

Case #1

15.3-in / 83 mS = **15.4 FPS = 10.5 MPH**
Single board, grain correct, good hold − little motion.
Good foot position. Approach not perpendicular.

Case #2



11-in / 83 mS = **11 FPS = 7.5 MPH**
Single ½-in. board, grain correct, good hold − little motion.
Good hand position, struck board off-center.

Case #3

11-in / 83 mS = **11 FPS = 7.5 MPH**
Single 1-in. board, grain correct, good hold – little motion.
Good foot position, struck board slightly low.

Case #4

26-in / 83 mS = **26 FPS = 17.7 MPH**
Single 1-in. board, grain correct, good hold − little motion.
Hand position unclear, struck board very slightly low.

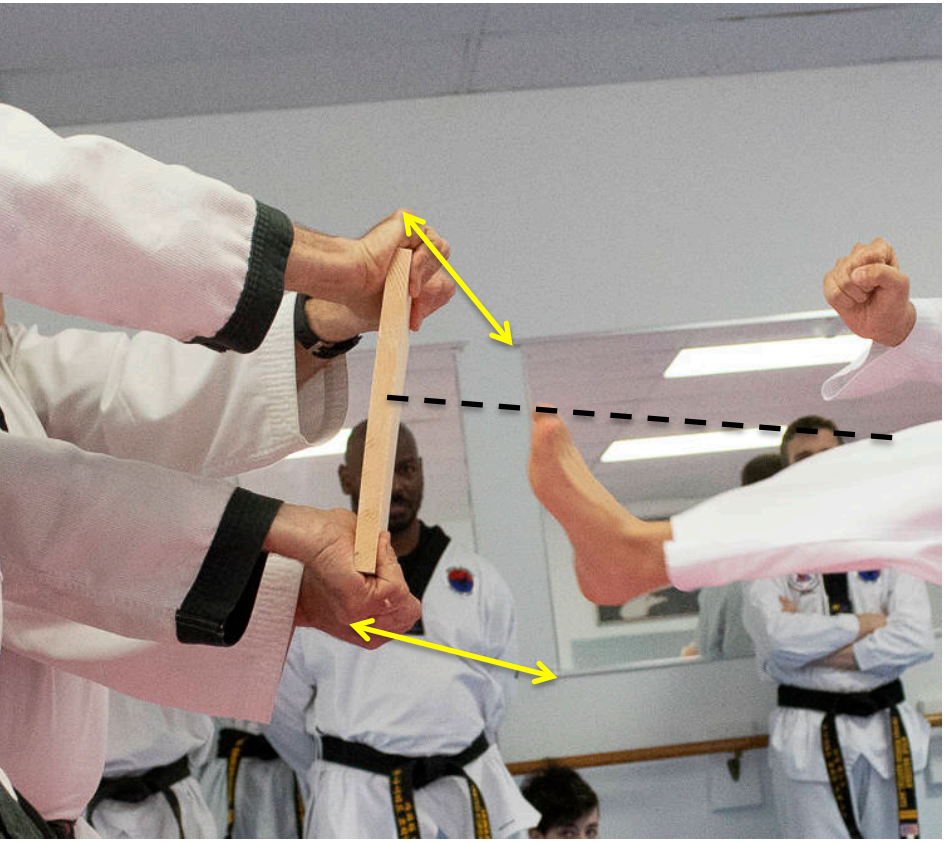
Case #5

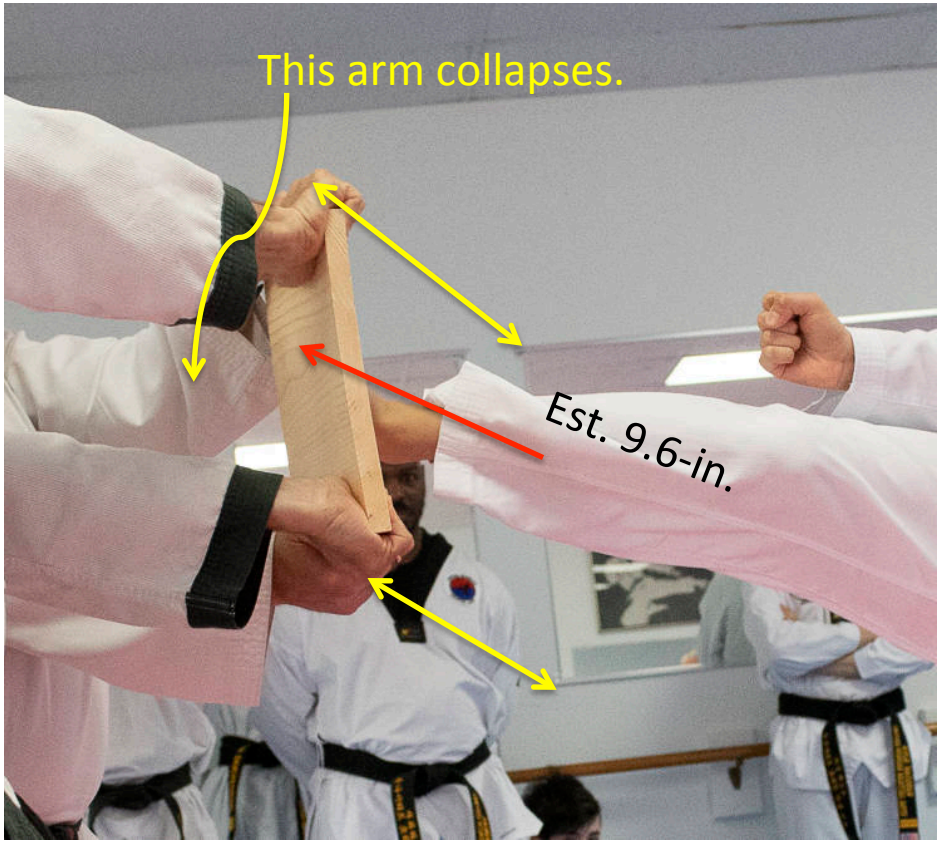
12-in / 83 mS = **12 FPS = 8.1 MPH**
Single 1-in. board, grain correct, good hold – little motion.
Good foot position, struck board at center.

Case #6

22-in / 83 mS = **22 FPS = 15 MPH**
Single ½ in. board, grain correct, good hold – little motion.
Good foot position, struck board at center.

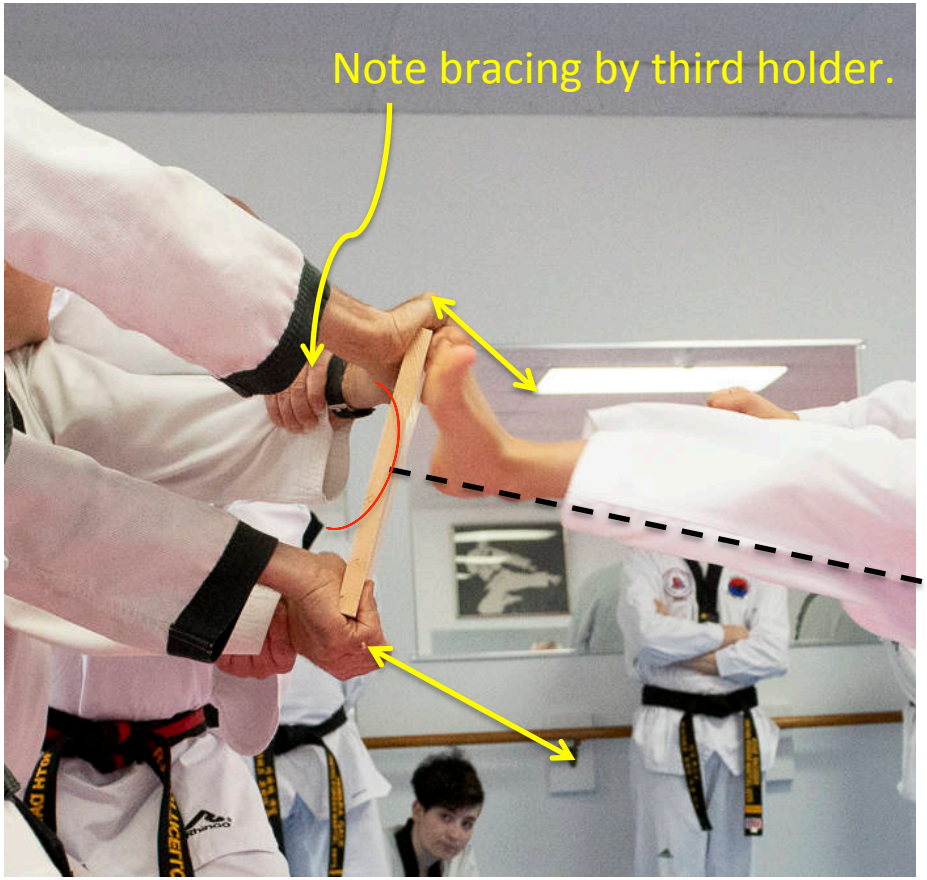
Case #7





9.6-in / 83 mS = **9.6 FPS = 6.5 MPH (may include decel.)**
Single 1 in. board, grain correct (curvature toward holders)
Board struck off center at top right.
Note two holders. Holder arm collapsing absorbing energy.
No break on first attempt.

Case #8

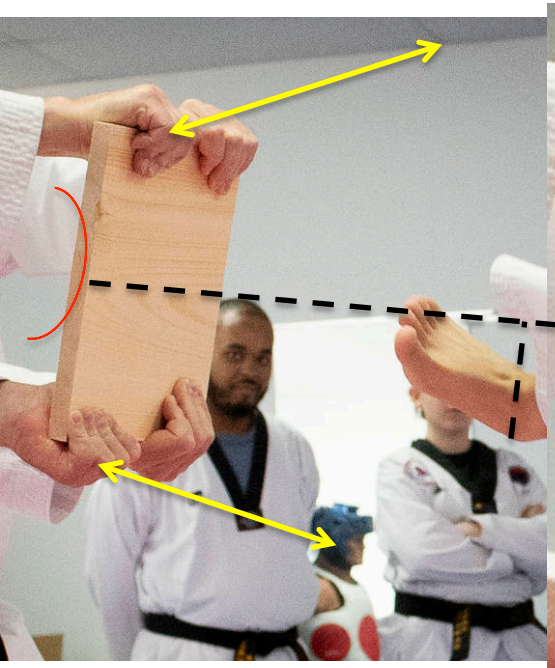


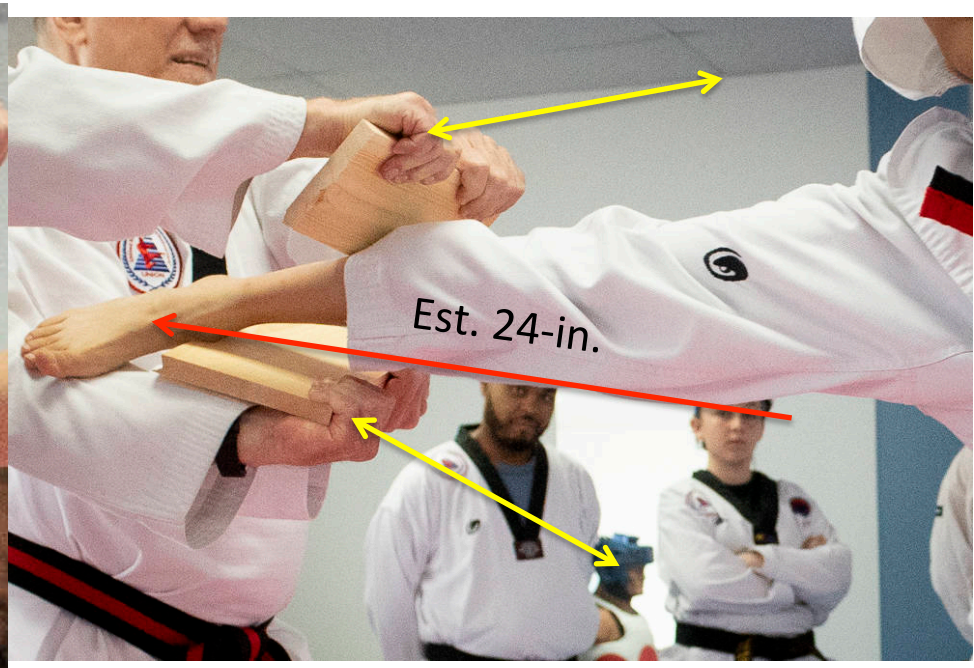
8-in / 83 mS = **8 FPS = 5.5 MPH (may include decel.)**
Single 1 in. board, grain correct (curvature toward holders)
Note two holders with a third **bracing** right holder.
Ball of foot strikes high and left.
Heel actually breaks board, is on centerline approach
Good break on second attempt.

Case #9

16-in / 83 mS = **16 FPS = 10.9 MPH**
Single 1 in. board, grain alignment ok, but curvature toward holders.
Note two holders.
Heel strikes center of board.
Heel below centerline on approach
Good break.

Case #10

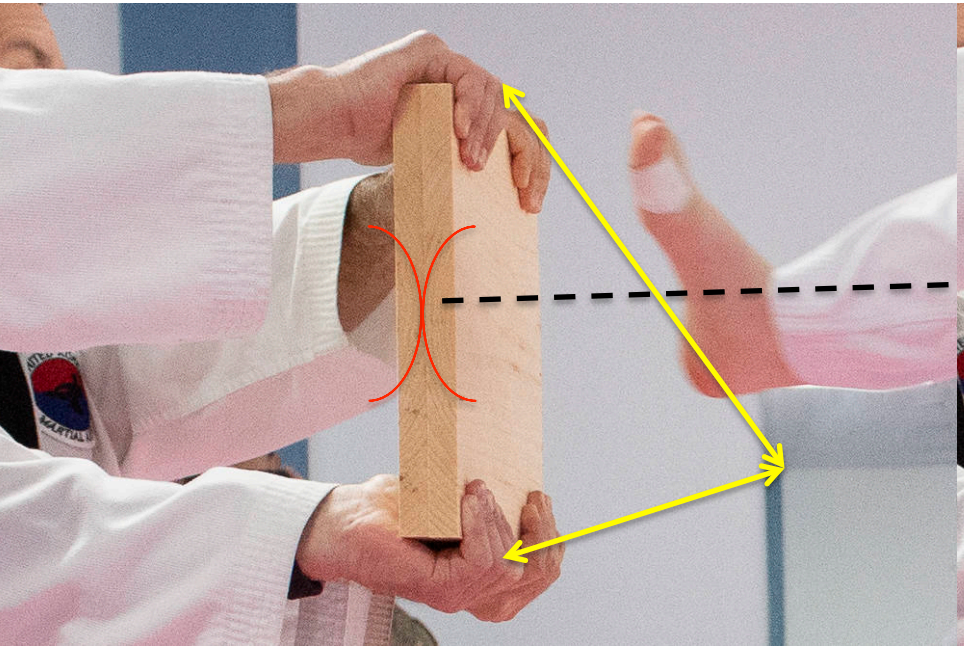


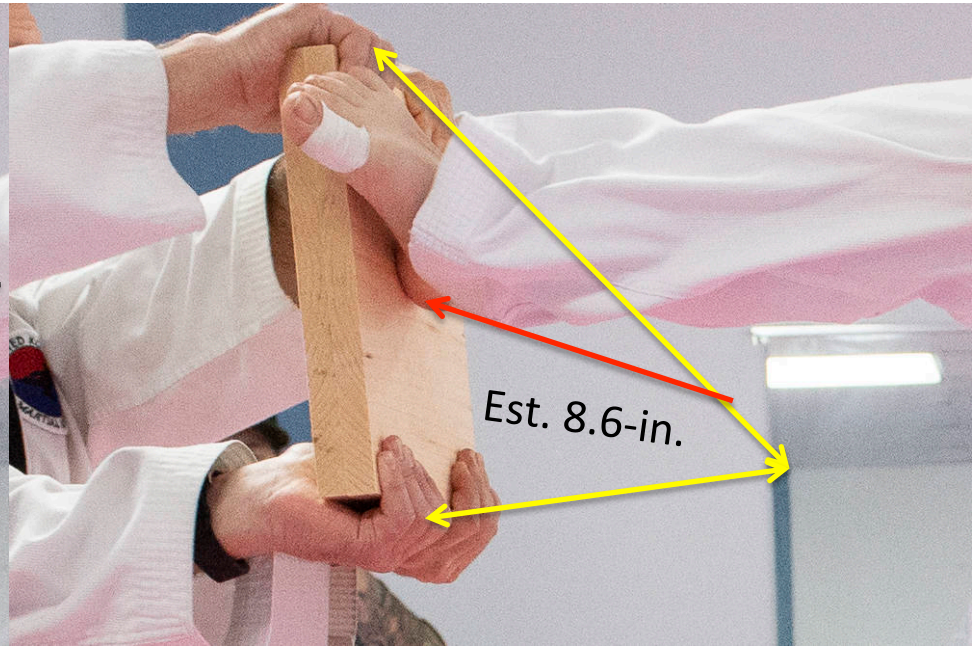


Check out the curvature of the board prior to breaking!!

24-in / 166 mS = **12 FPS = 8.2 MPH**
Single 1 in. board, grain alignment ok, but curvature toward holders.
Note two holders. Little holder movement.
Heel strikes center of board.
Heel below centerline on approach
Good break.

Case #11

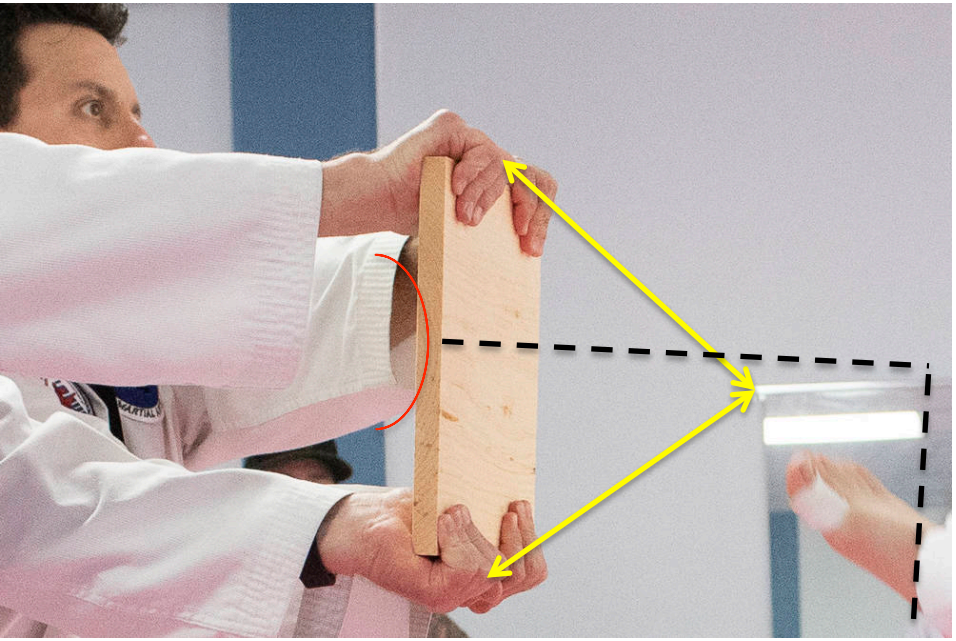


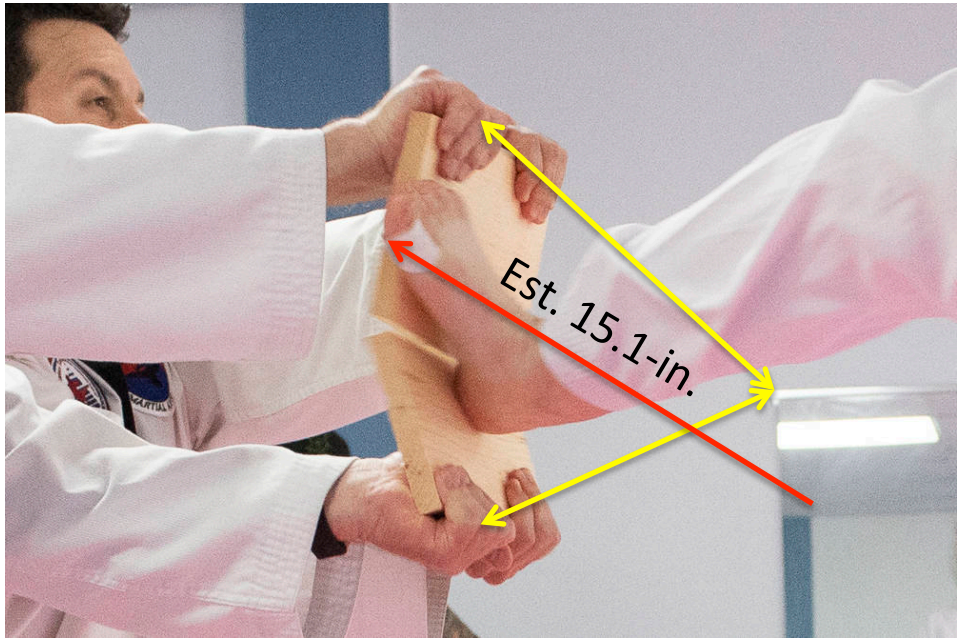


8.6-in / 83 mS = **8.6 FPS = 5.9 MPH**
TWO 1 in. boards, grain direction ok, but curvature MIXED!.
Note two holders. Significant holder movement.
Heel strikes center of board.
Heel below centerline on approach
No break on three attempts.

From a simple energy approximation, should require 1.41X velocity for two boards. Probably insufficient velocity.

Case #12





15.1-in / 83 mS = **15 FPS = 10 MPH**
Single 1 in. board, grain direction ok, but curvature toward holder.
Note two holders. Very little holder movement.
Heel strikes below center of board.
Heel below centerline on approach
Good break after three attempts with double boards. Note that est. velocity of this kick was DOUBLE the first attempt on the double boards in Case #11.

Yah... It broke. ☺

Case #13

15.3-in / 83 mS = **15 FPS = 10 MPH**

Two 1 in. boards, grain direction ok. No information on curvature.

Note two holders. Grain is vertical. Right hand holder buckled.

Foot strikes right of center of board (?).

Heel below centerline on approach

No break.

Case #14

13-in / 83 mS = **13 FPS = 8.9 MPH**
Two 1 in. boards, grain direction ok. No information on curvature.
Note two holders **plus one backup (not seen)**.
Heel below centerline on approach. Strike is **well-centered**.
Good break with a slower speed than earlier attempt. Probably due to better accuracy.

Case #15

22-in / 83 mS = **22 FPS = 15 MPH (probably higher due to angle of observer)**
One 1 in. board, grain direction ok. No information on curvature.
Note one holders **plus one bracing**.
Heel seems on centerline on approach. Strike is slightly high.
Foot position is non-ideal.
Good break.
V-squared wins the day!

Case #16

22-in / 83 mS = **22 FPS = 15 MPH**

THREE 1 in. board, grain direction ok. Curvatures aligned and inward, as shown.

Note two holders **plus one bracing**. Little holder movement on break.

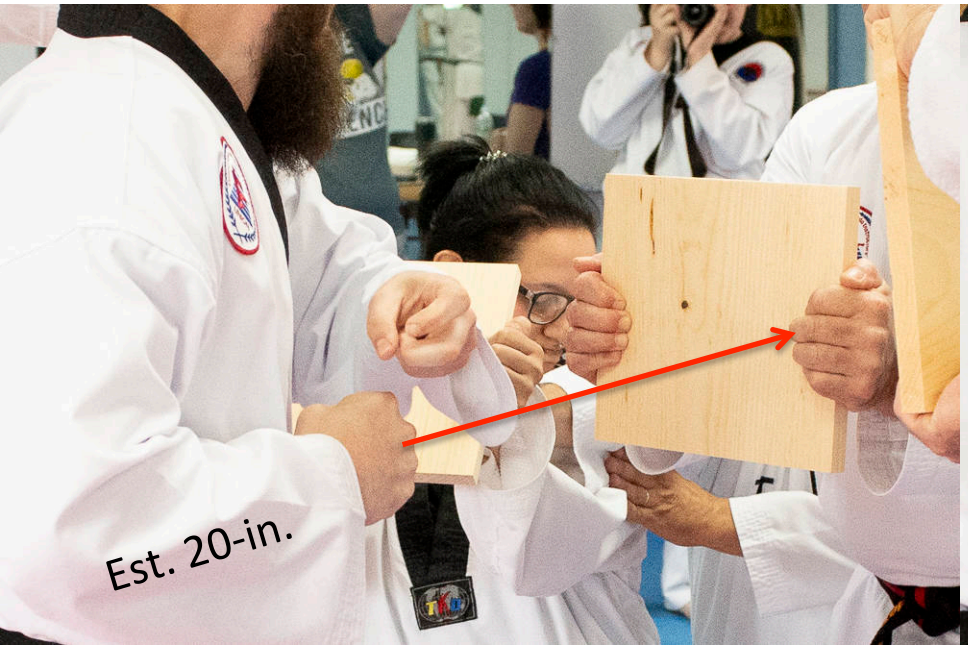
Heel below centerline on approach. Strike is slightly low.

Foot position is excellent.

Good break.

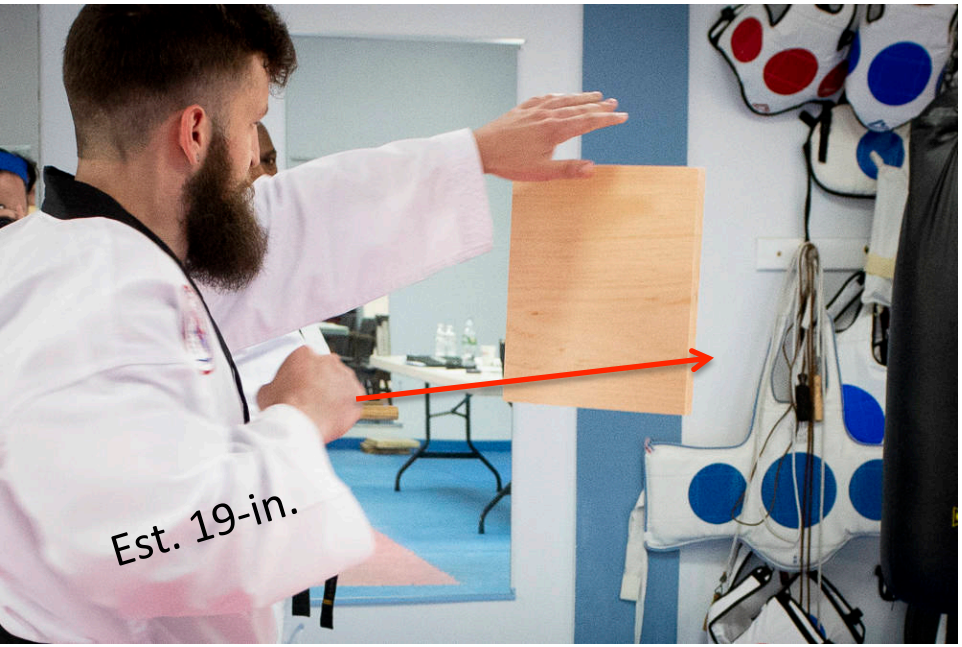
V-squared wins the day!

Case #17



Assume a 20-degree angle to the line of action. Increase calculations by 1.06X.
20-in / 83 mS = 20 FPS = 12.6 X 1.06 or **14 MPH ! (Minimum! Break was complete in less than the frame rate!)**
One 1 in. board, grain direction ok. Curvatures unknown.
Note one holder. Little holder movement on break.
Break is well centered.
This break may be fastest velocity observed, but we ran out of resolution.

Case #18



Assume a 20-degree angle to the line of action. Increase calculations by 1.06X.

19-in / 83 mS = 19 FPS = **13 MPH**

One 1 in. board, grain direction ok. Curvature unknown.

No holders, board is in freefall.

Break is well centered vertically.

Revision History

- Release – 13 OCT 2018
- Rev. A – 15 OCT 2018, corrected MPH errors