Pine Board Breaking in the Martial Arts

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Today, people all over the world use martial arts for recreation, competition, and self defense. Over the years powerful techniques have been developed and cultivated and a popular way to show these techniques is to break pine boards.

Board breaking represents a large force applied to a piece of wood for a short time. Since both force and instantaneous striking velocity are important, the analysis was undertaken relative to breaking energy. The boards were assumed to be standard 12 in. x 12 in, x ¾ in.White Pine *(P. Strobus)* held tightly at both ends (all striking energy goes into breaking the board.) The board was assumed to be free of defects (no high local stress concentrations) and modeled according to column loading. This means that the maximum energy that the board can store before fractures begin to propagate is given by

$$\mathbf{U_{max}=V^{*}\sigma_b/2E}$$

where σ_b is the breaking stress, V is the board volume, and E is Young's Modulus. Since the boards are largely breaking in tension, σ_b can be replaced with M_r, the modulus of rupture. The modulus of rupture is the highest tensile stress a material can undergo in bending.

Figure 1 shows a 3D representation of the breaking energy applied to the board as a function of apparent mass (m_a) and striking speed. Apparent mass is a function of technique. For a punch, someone could punch with only their arm, or they could put their shoulder, hip, or whole body into the strike. Striking speed is defined as the instantaneous velocity of the limb at the point of contact with the board. The base case is a fresh pine board with a volume of 0.0017 m^3. With M_r=0.061 GN/m^2 and E=8.81 GN/m^2, the breaking energy is 359 J. The energy required to break the board is shown as a horizontal plane with z=359 J. Any combination of striking speed and apparent mass above this plane will result in fracture, any combination below the plane will result in a bruised limb.

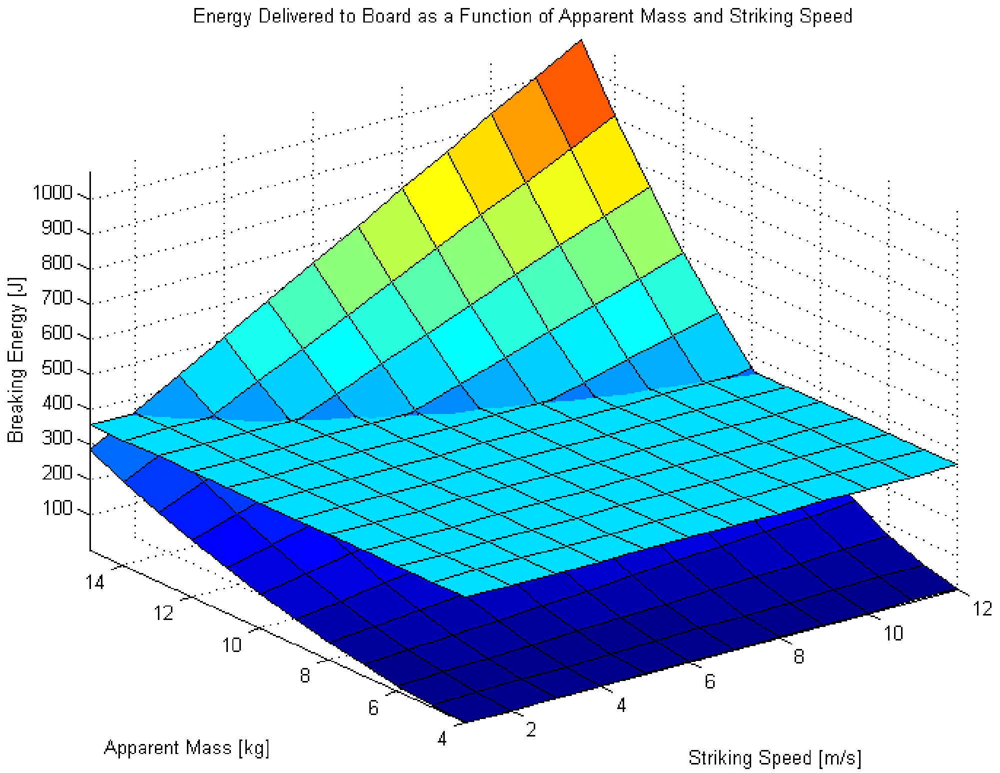

Figure 1. The energy delivered to a board is a function of striking speed and apparent mass. The horizontal plane represents the energy needed to break a standard adult board.

There are several recognized limitations with this analysis. First of all, the breaking stress energy is defined as the average energy per unit volume. During a strike, the stress energy is highly localized, and therefore neither shape nor geometry variations are adequately addressed. Secondly, at least some energy from the strike is used to move the board, and some is dissipated as heat and sound.

Overall, however, the predictions of the model are consistent with experiential evidence, and provide a meaningful estimate of parameters that can determine whether a given board will break or not.

Breaking of Boards Under Non-Idealized Holding Conditions

The above analysis could be considered a 'best case' scenario for breaking boards. In reality, however, even the best holders will move the board slightly. Also, many higher ranking students break a board that is held only at one end. How does this affect the required breaking energy?

One Handed Holds- Now the board is modeled as a cantilever beam. The martial artist must deliver enough energy to cause any deflections of the board in addition to the energy to break the board. This will be equal to the displacement of the beam multiplied by the force applied to cause that displacement. With a point load P applied in the middle of the board, the maximum deflection is given by:

$$\mathbf{D=5PL^3/(24EI)}$$

Assuming that the deflection is small and linear, multiplying this by the force that caused this displacement will give a reasonable approximation to the energy 'wasted' in this manner. Since E= force times distance, now the energy delivered to a board during a particular strike is:

$$\mathbf{E=1/2m_av^2 - 5P^2L^3/(24EI)}$$

But how do we find P? For this analysis we consider the impulse applied to the board. Since its original momentum is zero, we have the momentum of the strike (m_av) equal to the force of the strike multiplied by the time of application. Here the time of application is taken to be 0.25 s. This leads to the final equation for a one sided hold:

$$\mathbf{E=1/2m_av^2 - 5(m_av\,)L^3/(6EI)}$$

However, for the given parameters over a normal range of strikes, less than one joule is lost to move the board, which moves only 7 mm. In reality, a perfectly fixed cantilever beam is an unrealistic assumption. A loosely held board sweeps out a quarter circle with a radius of its length, so the average board particle moves pi*L/8 meters. A better equation is graphed in figure 2.

$$\mathbf{E=1/2m_av^2 - (m_av\,)L{*}pi/2}$$

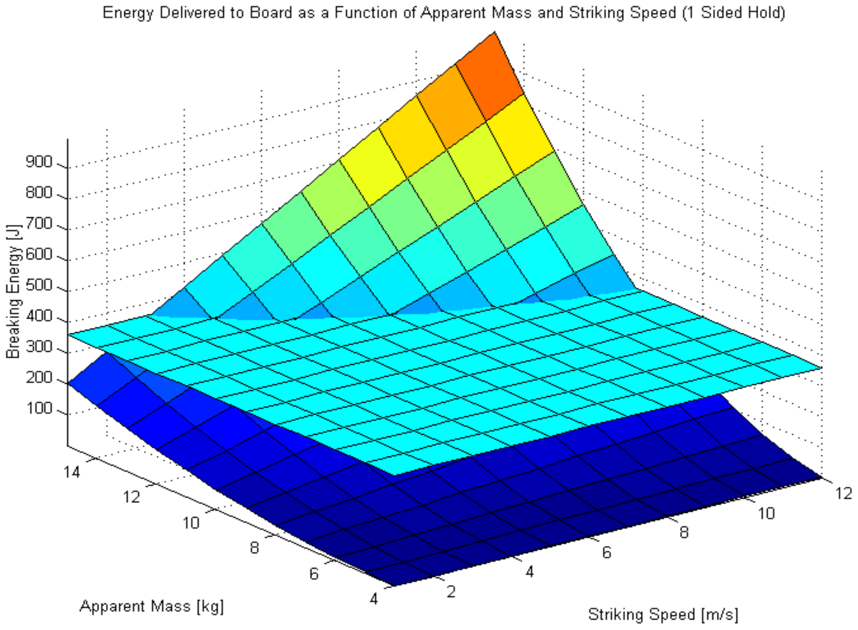

Figure 2. The energy delivered to a board is a function of striking speed and apparent mass for a one handed hold. Note that now the horizontal plane covers more of the breaking energy curve, signifying a more difficult break.

Two Sided Holds- A two sided hold in which the holders give can be modeled in several different ways. The amount that they give could be expressed as a fixed distance, or a fixed or percentage amount of energy or force absorbed. A percentage of the force absorbed is the best option, because the holders are applying a force, this will let the distance that the board moves be a function of the strike. With F as a fraction of the force absorbed by the holders, the board now feels the net force $Fnet=(1-F)\ (m_a v)/0.25$ s, which gives an acceleration to the board of $Fnet/m_b$. Since the board has this acceleration for the same 0.25 s and $W=Fnet*1/2a_b*t2$, the energy imparted to the board in a strike is:

$$\mathbf{E=1/2m_a v^2 - ((1-F)\ (m_a v\ ))^2\ /2\ m_b}$$

The results are plotted in figure 3 (F=0.80) and figure 4 (F=0.85). In general, for F values greater than 0.9 the difference is small. For 0.78<F<0.9 the difference becomes marked, and only a very powerful strike can fracture the board. Below this range the model breaks down as the board undergoes an acceleration that causes it to go away from the strike faster than the strike itself, so the board cannot be broken regardless of the strike. It is interesting to note that this model can also handle F values slightly greater than one, as when an adult will push a board against a child's strike to make it easier for them to break.

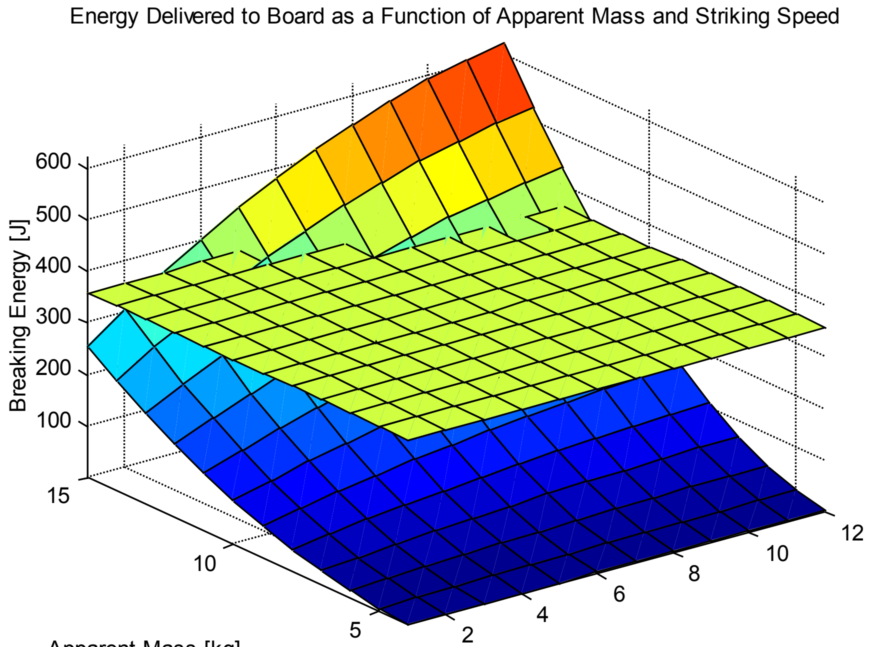

Figure 3. The energy delivered to a board is a function of striking speed and apparent mass for a two handed hold where the holders absorb 80% of the force. Note that now the horizontal plane covers most of the breaking energy curve, signifying a very difficult break

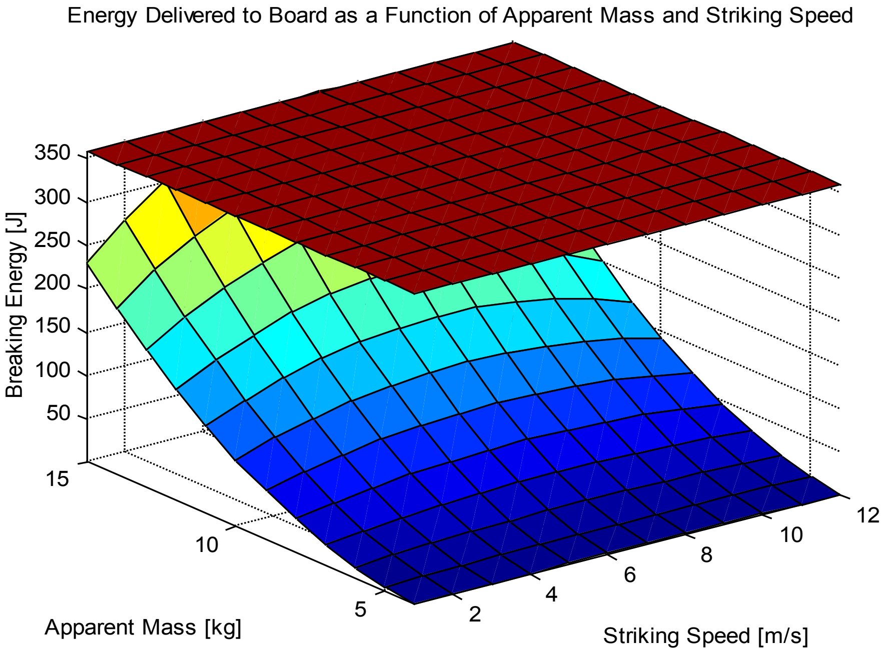

Figure 4. The energy delivered to a board is a function of striking speed and apparent mass for a two handed hold where the holders absorb 85% of the force. Note that now the horizontal plane covers most of the breaking energy curve, signifying a near impossible break.

With proper training, board breaking is an excellent way to demonstrate the beauty, power, and grace in martial arts and a scientific understanding of the mechanics behind it can greatly aid the martial artist.