Penetration Mechanics: A Force-Based Perspective on Energy and Momentum

Understanding how resistance, work, and deceleration govern penetration behavior

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Date: December 2025

Abstract

When people talk about arrow penetration, they often focus on kinetic energy, momentum, or drag equations. These ideas are helpful, but they do not directly explain what causes an arrow to stop. This paper explains penetration using basic Newtonian physics. Penetration happens when an arrow applies force against resistance. Kinetic energy limits how much work can be done, and momentum affects how quickly the arrow slows down, but neither alone determines penetration depth. This paper explains these ideas in a simple, force-based way.

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1. Introduction

Discussions about arrow penetration often turn into arguments about whether kinetic energy or momentum is more important. Some people also use fluid drag equations to explain penetration, especially when comparing heavy and light arrows.

These explanations often miss the most important question: **what actually stops the arrow?**

This paper explains penetration by focusing on forces and resistance. Kinetic energy and momentum are still important, but they support the explanation instead of replacing it.

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2. Starting with Newton's Laws

Newton's second law tells us that force causes changes in motion:

$$F = ma$$

When an arrow enters a target, it slows down because the target pushes back on it. This pushback is called resistance. The arrow continues to penetrate only while it can apply enough force to overcome that resistance.

In simple terms:

An arrow penetrates as long as the force it applies is greater than the force resisting it.

Newton's third law says that forces come in equal and opposite pairs. The arrow pushes on the target, and the target pushes back on the arrow. This equality does not cause the arrow to stop. The arrow slows down because a resisting force acts on it.

This idea applies to arrows, bullets, knives, and any object that penetrates material.

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3. What Kinetic Energy Tells Us

Kinetic energy is defined as:

$$KE = \frac{1}{2}mv^2$$

Kinetic energy tells us how much work an object can do. During penetration, work is done as the arrow cuts, compresses, and breaks material.

Work is written as:

$$Work = \int F\,dx$$

Kinetic energy sets the **total amount of work** the arrow can perform. However, it does not tell us:

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- How strong the resisting force is
- How fast the arrow slows down
- How resistance changes as the arrow goes deeper

Two arrows with the same kinetic energy can still behave very differently during penetration.

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4. What Momentum Tells Us

Momentum is defined as:

$$p = mv$$

Momentum describes how hard it is to stop an object. When an arrow stops, its momentum changes to zero. Newton's laws describe this using impulse:

$$\int F\, dt = \Delta p$$

This means that an arrow with more momentum usually takes longer to stop if the resisting force is similar.

At equal kinetic energy:

- A heavier arrow moves slower
- But it has more momentum
- It slows down over a longer time

Momentum affects **how long deceleration lasts**, not how much work the arrow can do.

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5. Why Drag Equations Are Often Misused

The fluid drag equation is often written as:

$$F_d = \frac{1}{2}\rho C_d A v^2$$

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This equation describes resistance in fluids like air or water. In these cases, resistance depends strongly on speed.

Penetration is different.

Most resistance during penetration comes from:

- Cutting and shearing material
- Compressing material in front of the arrow
- Friction along the shaft
- Breaking or fracturing material

These forces depend mainly on the type of material, the shape of the arrow, and how deep the arrow has traveled. Some parts of these forces can change with speed, especially in soft or fluid-like tissues, but they do not behave like fluid drag.

Using a fluid drag equation by itself ignores many of the forces that actually stop an arrow during penetration.

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6. A Force-Based View of Penetration

A more complete way to describe penetration is to combine all resisting forces:

$$F_{\text{resistance}} = F_{\text{shear}} + F_{\text{compression}} + F_{\text{fracture}} + F_{\text{friction}} + F_{\text{drag}}$$

Newton's third law guarantees that the force the arrow applies to the target is matched by an equal force from the target. The size of this force depends on the material and the arrow's design.

Penetration continues only while the arrow can supply enough force to overcome these resisting forces.

- Kinetic energy sets the work limit
- Momentum affects how long slowing takes
- Resistance determines whether penetration continues or stops

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7. Why This Matters

When penetration is explained using only energy or momentum:

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- Important resisting forces are ignored
- Results can be misunderstood
- Heavier arrows may be assumed to penetrate better by default

A force-based view explains why:

- Equal energy does not guarantee equal penetration
- Momentum affects timing, not resistance
- Arrow design and efficiency matter
- The same physics applies to all penetrating objects

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8. Conclusion

Penetration is controlled by force acting against resistance. Kinetic energy limits how much work can be done, and momentum affects how that work is delivered over time, but neither alone determines penetration depth. A simple force-based approach provides a clearer and more complete explanation of penetration mechanics.

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9. Resources

Halliday, D., Resnick, R., & Walker, J.
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Engineering Mechanics: Dynamics, 8th Edition.
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Impact Mechanics.
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