# A Refutation of Attempted Falsification of the Work-Energy Principle

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**Abstract**

In the paper "A thought experiment falsifies the work-energy principle," J.H. Mandlbaur proposes that a rocket operating at constant thrust and efficiency violates the work-energy principle due to the discrepancy between a constant fuel burn rate and the increasing mechanical work performed on the rocket as its velocity increases. This paper critiques that conclusion using standard Newtonian mechanics. We demonstrate that the apparent paradox arises from an elementary framing error: treating the rocket as a closed system while completely ignoring the kinetic energy of the expelled reaction mass. By analyzing the system in its entirety—incorporating the kinetic energy of the exhaust stream from the stationary frame of reference—we demonstrate that the work-energy theorem holds perfectly. Furthermore, we clarify that Mandlbaur's observation regarding the variable distribution of kinetic energy is not a falsification of classical mechanics, but rather a standard manifestation of the well-documented Oberth effect.

## 1 Introduction

In "A thought experiment falsifies the work-energy principle," [1] Mandlbaur presents a scenario involving a rocket lifting off from a zero-gravity platform with a constant thrust and constant efficiency engine. The author observes two distinct intervals of time, each lasting exactly one second.

In the first interval, starting from rest, the rocket covers a distance of 5 m. The work done on the rocket is calculated as $W = F \times 5$, where $F$ is the constant force of the rocket's thrust. In a later one-second interval, when the rocket is traveling at approximately 100 m/s, it covers a distance of 100 m. The work done on the rocket in this second interval is calculated as $20W = F \times 100$.

Mandlbaur argues that because the engine operates at constant thrust and constant efficiency, the "energy spent by the rocket in both instances must be exactly the same." From this premise, the author concludes that since the energy spent is identical but the work done on the rocket differs by a factor of 20, the work-energy principle is fundamentally false.

## 2 The Open System Fallacy

Mandlbaur's calculation of the mechanical work done on the rocket itself is correct. The mechanical power $P$ delivered to an object is the dot product of force and velocity ($P = F \cdot v$). Because thrust ($F$) remains constant while the rocket's velocity ($v$) increases, the rate at which kinetic energy is imparted to the rocket increases over time. Consequently, the work done on the rocket is indeed vastly greater at higher velocities.

The fundamental mathematical error in the thought experiment lies in the assumption that the "energy spent" by the rocket engine must directly equal the mechanical work done exclusively on the rocket body. A rocket is not an isolated, closed system; it propels itself by expelling reaction mass (exhaust) in the opposite direction.

The chemical potential energy liberated by the rocket's engine is not converted solely into the kinetic energy of the rocket payload. Instead, it is converted into the kinetic energy of the rocket *plus* the kinetic energy of the expelled exhaust. Mandlbaur's analysis completely omits the kinetic energy of the exhaust in the observer's (stationary platform) reference frame, a critical component of classical mechanics required when applying the work-energy theorem to a variable-mass system [2].

## 3 System-Wide Energy Conservation

To rigorously apply the work-energy principle, we must evaluate the kinetic energy of the entire closed system: the rocket and its expelled reaction mass. We achieve this by analyzing the system over an infinitesimal time interval $dt$.

Let $M$ be the instantaneous mass of the rocket at time $t$, traveling at velocity $v$ relative to the stationary platform. In the time interval $dt$, the engine burns and expels a small mass $dm$ (where $dm > 0$). The exhaust is expelled at a constant velocity $v_e$ relative to the rocket, meaning its velocity in the stationary frame is $(v - v_e)$.

At time $t$, the total kinetic energy $K(t)$ of the system (comprising the rocket and the unburned fuel it carries) is:

$$K(t) = \frac{1}{2}Mv^2 \tag{1}$$

At time $t + dt$, the rocket has a reduced mass $(M - dm)$ and an increased velocity $(v + dv)$. The expelled exhaust has mass $dm$ and velocity $(v - v_e)$. The total kinetic energy $K(t + dt)$ is:

$$K(t + dt) = \frac{1}{2}(M - dm)(v + dv)^2 + \frac{1}{2}dm(v - v_e)^2 \tag{2}$$

Expanding the squared terms gives:

$$K(t + dt) = \frac{1}{2}(M - dm)(v^2 + 2vdv + dv^2) + \frac{1}{2}dm(v^2 - 2vv_e + v_e^2) \tag{3}$$

By dropping the negligible second-order infinitesimal terms ($dv^2$ and $dm \cdot dv$), the equation simplifies to:

$$K(t + dt) \approx \frac{1}{2}Mv^2 + Mvdv - \frac{1}{2}dmv^2 + \frac{1}{2}dmv^2 - dmvv_e + \frac{1}{2}dmv_e^2 \tag{4}$$

Canceling the $-\frac{1}{2}dmv^2$ and $+\frac{1}{2}dmv^2$ terms, and factoring out $v$, we find:

$$K(t + dt) = \frac{1}{2}Mv^2 + v(Mdv - dmv_e) + \frac{1}{2}dmv_e^2 \tag{5}$$

By the law of conservation of momentum in a zero-gravity vacuum, the impulse on the rocket equals the momentum carried away by the exhaust, yielding $Mdv = dmv_e$. Therefore, the middle term $v(Mdv - dmv_e)$ evaluates to exactly zero. We are left with:

$$K(t + dt) = \frac{1}{2}Mv^2 + \frac{1}{2}dmv_e^2 = K(t) + \frac{1}{2}dmv_e^2 \tag{6}$$

The change in total system kinetic energy $dK$ over the interval $dt$ is:

$$dK = \frac{1}{2}dmv_e^2 \tag{7}$$

Dividing by $dt$ provides the total rate of mechanical energy increase (total power) in the system:

$$\frac{dK}{dt} = \frac{1}{2}\dot{m}v_e^2 \tag{8}$$

Where $\dot{m}$ is the constant mass flow rate of the fuel. This value $\frac{1}{2}\dot{m}v_e^2$ perfectly matches the constant chemical power output of the engine. The work-energy theorem holds flawlessly: the constant energy spent by the engine precisely matches the constant rate of total kinetic energy increase across the whole system.

## 4 The Oberth Effect and the Kinetic Energy Reservoir

The paradox Mandlbaur [1] highlights—that the mechanical power delivered to the rocket body ($P_{rocket} = F \cdot v = \dot{m}v_e v$) continually increases and eventually exceeds the engine's chemical power ($\frac{1}{2}\dot{m}v_e^2$)—is completely accurate but misinterpreted.

This phenomenon is standard classical mechanics and is known in astrodynamics as the Oberth effect. The extra energy driving the rocket at high speeds does not come from nowhere; it is extracted from the kinetic energy previously stored in the unburned propellant.

Before combustion, the fuel inside the rocket moves at velocity $v$, possessing a significant kinetic energy relative to the stationary platform. After combustion, if $v > v_e$, the exhaust is left moving in the same direction as the rocket, but at a much slower velocity $(v - v_e)$. Because the exhaust is decelerated relative to the stationary frame, it possesses *less* kinetic energy after the burn than it did before.

The energy difference between the fast-moving unburned fuel and the slower-moving exhaust is mechanically transferred directly into the rocket body. Thus, the total mechanical power propelling the rocket at high speeds is the sum of two perfectly conserved quantities: the chemical energy of the fuel plus the kinetic energy "robbed" from the decelerating reaction mass.

## 5 Conclusion

The thought experiment presented in "A thought experiment falsifies the work-energy principle" [1] does not expose a flaw in classical physics. Instead, it demonstrates a well-understood variable-mass dynamic, but incorrectly analyzes it by applying conservation principles to a non-isolated subsystem (the rocket alone) while discarding the reaction mass. When the full closed system is rigorously accounted for using differential calculus, the work-energy principle remains perfectly valid. The observation that work done on the vehicle scales with velocity simply confirms that the rocket engine redistributes an increasing share of kinetic energy from its propellant reservoir into the vehicle payload as its velocity increases.

## References


[1] Mandlbaur, J.H. "A thought experiment falsifies the work-energy principle." Baur Research CC, Randburg, South Africa. Preprint available at: `https://www.researchgate.net/publication/363585704_A_thought_experiment_falsifies_the_work-energy_principle`.

[2] Halliday, D. and Resnick, R. (1981). *Fundamentals of Physics* (2nd ed., extended version). John Wiley & Sons, Inc., New York, pp. 93–100.