Sling Effect – Angle Linear Momentum Conversion Motor

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Abstract

This paper investigates the principles and potential of rotational catapult mechanisms, specifically the sling effect, as efficient converters of angular momentum into linear momentum for propulsion and projectile acceleration. Building on *Anglemetric Theory*, a framework developed emphasizing fundamental rotational physics, this work demonstrates how continuous rotational acceleration enables higher impulse delivery and energy efficiency compared to linear methods. Through theoretical analysis and thought experiments, it illustrates momentum conservation via angular-linear transformations and the inherent advantages of rotational systems, including controlled acceleration, gyroscopic stabilization, scalability, silent operation, and energy regeneration. Practical considerations such as centripetal force constraints and recoil dynamics are discussed. The findings suggest that sling-based rotational propulsion offers a promising, scalable alternative for applications ranging from terrestrial launch systems to advanced aerospace propulsion.

1 Introduction

The sling has been known to humanity since ancient times. The biblical confrontation between David and Goliath is a well-known example, and many civilizations from the ancient Greeks and Romans to the Incas, used the principles of rotational launch mechanics for warfare and hunting. With the advent and spread of gunpowder weapons, these sling-based systems were gradually replaced by devices favoring direct linear acceleration.

A sling is a hand-operated projectile launcher composed of two flexible cords connected by a central pouch designed to cradle a projectile. When rotated about an axis by the operator, the sling stores kinetic energy in the form of angular momentum, which is converted to linear momentum upon the timed release of one cord, propelling the projectile toward the target.

Unlike elastic projectile launchers such as slingshots or bows, which rely on the instantaneous release of stored elastic energy, the sling allows the operator to continuously accelerate the projectile over an extended arc of motion. This enables the build-up of significant kinetic energy using relatively modest muscle force. With sufficient skill and sling length, projectile speeds can rival or exceed those of traditional bows, while far surpassing typical handheld slingshots.

Elite athletes showcase the practical advantage of rotational acceleration. In the hammer throw, competitors spin a 7.26 kg ball on a wire multiple rotations before release [1]. This mechanism commonly achieves release speeds around 29 m/s, with record men's throws exceeding 86 m, far beyond what the shot put (essentially a linear throw of the same mass) achieves, whose world record stands at about 23 m, with release speeds typically around 14 m/s. In Highland Games weight-throw events [2], athletes also spin a heavy implement (often 12–25 kg) through rotations to release. This method consistently outperforms attempts at linear projection for the same effort [3]. Thus, systems that utilize continuous rotational acceleration (like a sling) can generate far higher projectile speeds and ranges than linear throwing devices, provided the rotational path and timing are properly managed.

The performance difference arises from the way force is applied. In a linear throw, the acceleration path is limited to the arm's extension, giving the projectile only a brief window to gain speed. In a rotational throw, an athlete (or sling mechanism) can apply force over multiple revolutions, steadily increasing tangential velocity before release. This extended application of torque allows the final speed to far exceed what can be achieved in a single straight-line push.

The performance difference between linear and rotational projectile acceleration fundamentally comes down to the concept of *impulse*, defined as the integral of force over time, which determines the change in momentum of the projectile:

$$J = \int F(t)\, dt = \Delta p = m \Delta v, \tag{1}$$

where J is the impulse, $F(t)$ the applied force, m the mass of the projectile, and Δv its change in velocity.

In linear acceleration systems, the projectile travels along a short path, limiting the time Δt_{linear} during which force can be applied:

$$J_{\text{linear}} = F \times \Delta t_{\text{linear}}. \tag{2}$$

In contrast, rotational systems enable the application of force over multiple revolutions, effectively extending the interaction time by a factor proportional to the number of rotations N and the rotation period T_{rot}:

$$J_{\text{rot}} = \int F(t)\, dt \approx F \times N \times T_{\text{rot}}. \tag{3}$$

This longer application time allows rotational mechanisms to impart significantly greater impulse, resulting in higher projectile velocities compared to their linear counterparts.

Rotational systems, much like levers, provide a form of mechanical advantage. While levers reduce the force required to move a load by increasing the distance over which that force is applied, rotational mechanisms offer an advantage by enabling the accumulation of higher projectile velocities within a compact spatial footprint. Consequently, rotary systems can deliver greater kinetic energy to the payload without the need for large linear acceleration paths, making them especially advantageous in space-constrained or efficiency-critical applications.

In the modern era, with the development of high-efficiency electric motors and precise electronic control systems, rotational mechanisms for accelerating projectiles are worth revisiting. Such systems present several advantages for research and practical application. We highlight below the primary advantages of these systems.

1.1 Controlled acceleration and deceleration

Modern electric drives, combined with feedback control systems, enable precise shaping of motion profiles. This reduces peak mechanical stresses on both the projectile and the launcher, while allowing for accurate tuning of release velocity and timing [4]. In sling-based systems, such control directly improves trajectory predictability and repeatability.

1.2 Versatility and Scalability

Rotational sling-based systems offer wide applicability across various sizes and functions. They can be adapted for uses ranging from silent drone propulsion and precise payload delivery to mechanical transportation. This scalability allows the same core mechanics to propel everything from micro-drones to manned vehicles, with designs tailored to meet specific force and velocity requirements.

1.3 High efficiency and sustainability (no combustion required)

Traditional combustion-based propulsion systems, including firearms and engines, typically convert only about 30–40% of the chemical energy in their fuel into useful kinetic energy, with the remainder lost as heat, sound, and inefficiencies in combustion and mechanical processes [5]. In contrast, modern electric motors can achieve efficiencies exceeding 90%, directly converting electrical energy into mechanical rotation with minimal waste [6]. Moreover, electric sling propulsion systems eliminate the need for fuel manufacturing, storage, and handling, reducing environmental impact and logistical complexity. The reusable nature of electric motors further enhances sustainability, enabling long-term, cost-effective operation without the consumable resources required by combustion-based systems.

1.4 Silent operation

Unlike combustion-based propulsion systems, which generate significant noise from explosions and exhaust, rotational acceleration mechanisms operate with minimal acoustic signature. The absence of combustion and the smooth, continuous nature of electric motor-driven rotation result in quieter operation, an advantage for stealth applications and environments where noise pollution must be minimized.

1.5 Energy regeneration

The sling mechanism itself has a rotating mass, which requires energy to maintain its motion. However, this rotational energy can be largely recovered by employing regenerative braking systems that slow down the rotating parts, converting their kinetic energy back into electrical energy. As a result, the net energy consumed corresponds primarily to the kinetic energy transferred to the projectile or craft. Furthermore, if the payload can tolerate high acceleration and deceleration forces, a secondary sling mechanism can be used to decelerate it, allowing for the recovery of its kinetic energy through the same regenerative process. This enables a closed-loop propulsion cycle that significantly improves overall system efficiency.

1.6 Gyroscopic Stabilization

Rotational systems benefit from inherent stability provided by gyroscopic effects [7]. This natural stability reduces the reliance on complex electronic feedback systems typically required to maintain accurate aiming on unstable platforms, such as ships or other moving vehicles. As a result, these systems can offer improved reliability and simplified control in dynamic environments.

2 Conceptual Framework: The Anglemetric Theory

Anglemetric Theory is a theoretical framework developed throughout the author's technical career, based on independent research into the fundamental principles of physics, with particular emphasis on rotational dynamics and geometry. Observations of natural phenomena, from small scale fluid dynamics to large scale planetary motion, consistently reveal that rotational motion emerges as a direct consequence of the conservation of momentum.

The term *Anglemetric* arises from the premise that angles constitute the most fundamental units of physical measurement, embodying both unicity and structure. This framework, rooted in Newtonian mechanics, uses angular relationships to provide deeper explanations for physical behavior. One of its central principles is that, since momentum must be conserved, linear momentum can transform into angular momentum and vice versa. Within this framework, energy is defined as movement; energy is manifestation of motion itself.

While Anglemetric Theory encompasses multiple principles, only those directly relevant to propulsion will be addressed here. A comprehensive presentation of the theory will be reserved for a dedicated publication. The present work focuses specifically on the angular-to-linear momentum transformation as it applies to rotational propulsion systems.

To illustrate these concepts from first principles, two physical scenarios will be presented. The first examines fluid dynamics and the transformation of momentum within a moving medium. The second addresses mechanical rotation and its conversion to linear motion. Both scenarios demonstrate the fundamental relationship between linear and angular momentum, providing the basis for the sling effect discussed in this paper.

3 Scenarios

3.1 Scenario 1: Isolated Fluidic System and Vortex Formation

To illustrate the natural emergence of rotational motion from momentum conservation, consider a channel containing water in steady, laminar flow. Introducing a fixed obstacle at the channel's midpoint forces the fluid to redirect around it. Upstream of the obstacle, the flow remains linear and stable; however, in the wake region downstream, vortices spontaneously form.

This occurs because water particles entering the wake carry forward (translational) momentum as well as lateral motion induced by the obstruction. The resulting velocity components give these particles a greater total kinetic energy than those moving strictly linearly.

Since the obstacle is static, it cannot absorb all the incoming momentum. Instead, the flow reorganizes locally, converting part of the linear momentum into rotational motion through vortex formation. This example demonstrates a general principle: when direct transfer of linear momentum is restricted, systems naturally generate angular motion to preserve both total momentum and energy.

3.2 Scenario 2: Interaction of Two Spheres in Deep Space

To illustrate the bidirectional conversion between angular and linear momentum, consider two identical spheres floating in deep space, far from any other masses or external forces. Their initial separation is large enough that no interactions occur until they approach one another. From a distance, only their trajectories are visible, surface details such as spin cannot be observed.

In the first case, the spheres are on a direct collision course, moving slowly toward each other with equal and opposite linear momentum. If the collision is perfectly elastic, each sphere simply reverses direction, retracing its incoming path.

In the second case, the approach is identical, but after the collision the spheres' paths deviate from simple reversal. This outcome can only occur if one or both spheres possessed angular momentum before impact. The collision converts part of this rotational momentum into linear momentum, altering their trajectories. This demonstrates the reciprocal nature of momentum transformation: angular momentum can be exchanged for linear momentum just as linear momentum can generate rotation.

3.3 Further Thinking About Momentum

The two scenarios above illustrate how momentum is conserved through conversion between linear and angular forms. In the fluid case, when direct particle motion is impeded, momentum is redirected, either dissipating as heat (itself a form of microscopic motion) or reorganizing into rotational structures.

In the sphere collision case, both linear and angular momentum must be considered. The proportion of momentum exchanged depends on the surface characteristics, which determine the degree to which angular momentum is transferred. At a microscopic level, this transfer can be understood as the sum of many individual interactions between the constituent particles of each sphere's surface.

Angular momentum attributed to a macroscopic body is, in fact, the collective orbital motion of its constituent particles around the body's center of mass. If those particles themselves possess spin, the same hierarchical logic applies: each particle's rotation emerges from even smaller constituents orbiting their own centers of mass. Pure angular momentum would exist only for an indivisible particle, yet even then, a subdivision into notional regions allows the same analysis to persist.

The same reasoning extends to vortices in fluids: the apparent bulk rotation is the aggregated orbital momentum of fluid particles around a shared center, conserving the system's total momentum.

4 Angular-to-Linear Momentum Conversion in a Rigid System

To illustrate the transformation of rotational motion into translational motion, consider two rigidly connected disks, A and B, in deep space, isolated from external forces.

Disk A

- Mass: 100 kg
- Radius: 0.95 m
- Center of mass at $(0, 0)$

Disk B

- Mass: 1 kg
- Radius: 0.05 m
- Center of mass at $(1.0\text{ m}, 0)$

System Center of Mass

The center of mass is given by:

$$x_{\text{cm}} = \frac{m_A x_A + m_B x_B}{m_A + m_B}$$

Substituting values:

$$x_{\text{cm}} = \frac{100 \times 0 + 1 \times 1}{100 + 1} = \frac{1}{101} \approx 0.0099\text{ m}$$

The system rotates about this point with angular velocity $\omega = 2\pi$ rad/s.

Linear Velocities of the Disk Centers

For Disk A:

$$v_A = \omega \cdot r_A \approx 2\pi \times 0.0099 \approx 0.062 \text{ m/s}$$

For Disk B:

$$v_B = \omega \cdot r_B \approx 2\pi \times (1 - 0.0099) \approx 6.22 \text{ m/s}$$

Each disk therefore has:

- **Linear momentum** from the tangential motion of its center of mass.
- **Intrinsic angular momentum** from spinning about its own center.

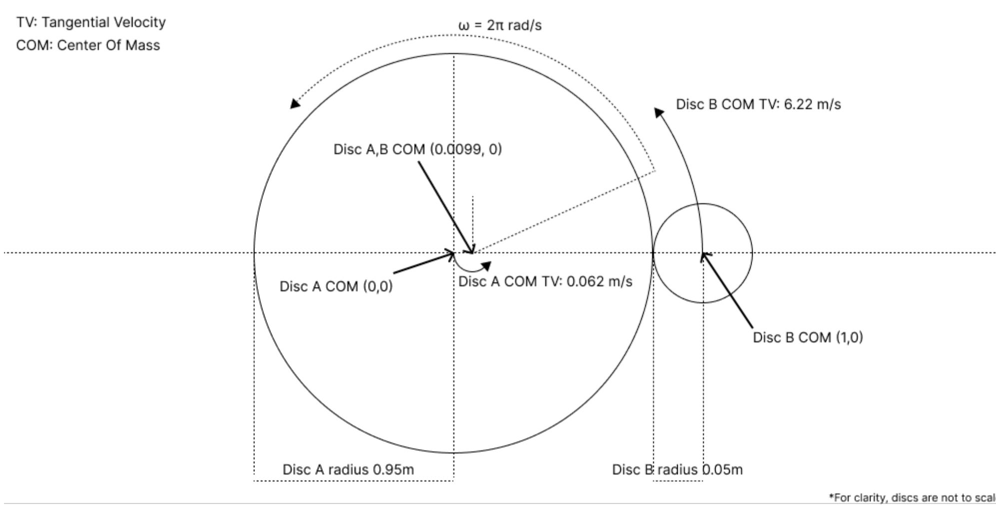

Figure 1: Two-disc sling system

Moment of Release

If the rigid connection is suddenly broken, each disk continues independently, preserving the system's total linear and angular momentum. Disk A moves at 0.062 m/s and Disk B at 6.22 m/s, matching their previous tangential speeds.

This illustrates how a single rotational system can be decomposed into independent linear motions, demonstrating the fundamental principle behind sling-based propulsion: rotational energy can be redistributed into translational energy in a controlled way.

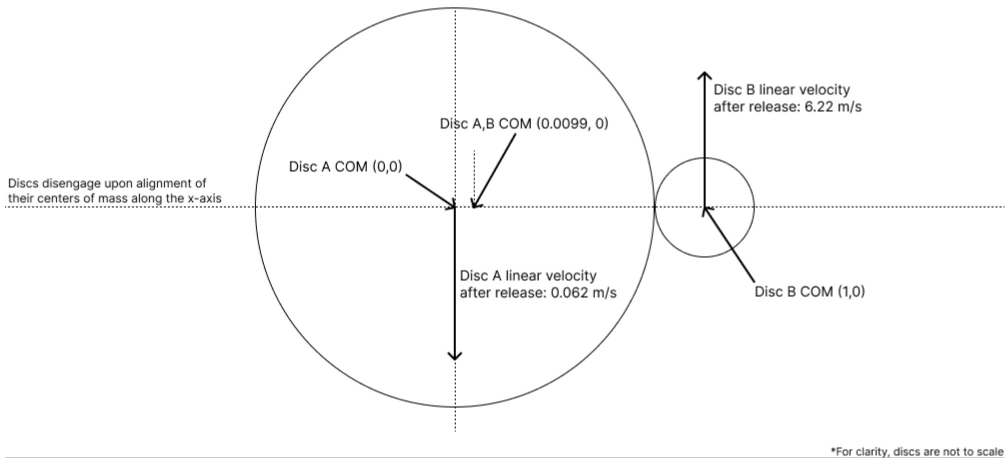

Figure 2: Discs disengage

4.1 Comparing to a Linear System

Consider the same two discs, A and B, initially touching and aligned along a line, with masses $m_A = 100\,\mathrm{kg}$ and $m_B = 1\,\mathrm{kg}$. Suppose disc A pushes disc B directly, imparting momentum linearly without any rotation. The goal is for disc B to reach the same final velocity $v_B \approx 6.22\,\mathrm{m/s}$ as observed in the rotational thought experiment upon release.

To conserve linear momentum, disc A must recoil with velocity v_A such that:

$$m_A v_A + m_B v_B = 0$$

Solving for v_A:

$$v_A = -\frac{m_B}{m_A} v_B = -\frac{1}{100} \times 6.22 = -0.0622\,\mathrm{m/s}$$

The negative sign indicates disc A moves in the opposite direction to disc B. These velocities match those seen in the rotational system after release ($v_A \approx 0.062\,\mathrm{m/s}$, $v_B \approx 6.22\,\mathrm{m/s}$).

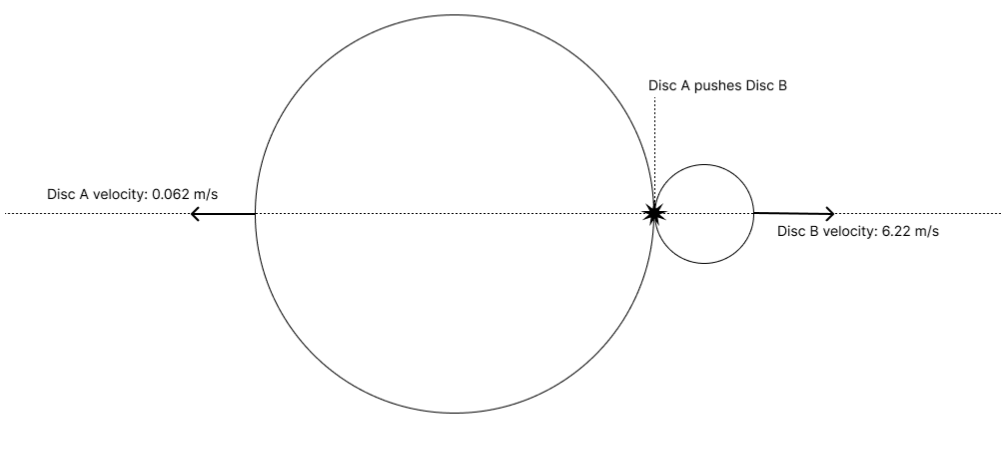

Figure 3: Linear push

While the final velocities and momentum conservation are the same in both systems, the *manner* in which the momentum is transferred differs significantly:

- **Rotational system:** Momentum transfer occurs over the full rotation period as disc B is gradually accelerated tangentially by continuous rotation. The force is applied smoothly and repeatedly, allowing efficient and controlled energy delivery.
- **Linear system:** The force must be applied in a single, direct push over the short interaction distance where the discs are in contact. Achieving the same final velocity requires a sudden, high-intensity impulse or a sufficiently long acceleration run, which can be less energy efficient and induce higher mechanical stresses.

Thus, the rotational system offers a more controlled and time-extended method of velocity transfer, reducing instantaneous force demands while achieving identical momentum outcomes.

4.2 Impulse Analysis for Rotational and Linear Momentum Transfer

Recall that impulse J is the integral of force over time, and it equals the change in momentum:

$$J = \int F\,dt = \Delta p = m\Delta v$$

Rotational System Impulse

Assume the rotational system completes one full revolution ($T = \frac{2\pi}{\omega}$) to accelerate disc B from rest to the target tangential velocity v_B.

The time for one revolution is:

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{2\pi} = 1 \text{ s}$$

(using $\omega = 2\pi$ rad/s from the thought experiment).

The required impulse on disc B is:

$$J_{\text{rot}} = m_B v_B = 1 \text{ kg} \times 6.22 \text{ m/s} = 6.22 \text{ N} \cdot \text{s}$$

The average force applied during one revolution is:

$$F_{\text{avg,rot}} = \frac{J_{\text{rot}}}{T} = \frac{6.22}{1} = 6.22 \text{ N}$$

If more revolutions are allowed, the force decreases proportionally:

$$F_{\text{avg,rot}} = \frac{J_{\text{rot}}}{nT} = \frac{6.22}{n}$$

where n is the number of revolutions.

Linear System Impulse

For the linear push, assume the momentum transfer is instantaneous, i.e., the impulse is applied over a very short time interval $\Delta t \to 0$. Then the average force is:

$$F_{\text{avg,lin}} = \frac{J_{\text{lin}}}{\Delta t}$$

where

$$J_{\text{lin}} = m_B v_B = 6.22 \text{ N} \cdot \text{s}$$

Because Δt is very small, $F_{\text{avg,lin}}$ is very large, implying a sudden, high-stress force impulse.

Summary

This impulse analysis quantitatively illustrates why the rotational system is advantageous: by increasing the time over which momentum transfer occurs (via rotation), the required instantaneous force drops, resulting in less mechanical stress and potentially higher efficiency.

4.3 The Centripetal Force Caveat in Rotational Systems

While rotational propulsion systems offer advantages in controlled momentum transfer and efficiency, they also impose unique constraints due to centripetal forces acting on the projectile or payload during acceleration.

Centripetal Force Requirement: Any mass moving in a circular path experiences an inward-directed centripetal force F_c necessary to maintain its curved trajectory:

$$F_c = m\frac{v^2}{r}$$

where

- m is the mass of the projectile,
- v is the tangential velocity, and
- r is the radius of the rotation.

This force must be supplied continuously by the rotating mechanism to keep the projectile moving along its circular path before release.

Implications:

- For a given mass and desired exit velocity, the centripetal force requirement grows quadratically with velocity and inversely with radius. This can result in extremely high mechanical stresses on the sling components, especially at high speeds or small radii.
- The payload itself experiences these centripetal accelerations, which may limit the types of cargo or projectiles that can safely be accelerated without damage.

- The design must balance radius, rotational speed, and material strength to manage these forces effectively.

Comparison to Linear Systems: Linear propulsion systems do not require centripetal force for momentum transfer, so they avoid this specific mechanical stress. However, as previously discussed, they must compensate with higher instantaneous forces and longer acceleration distances.

Summary: The centripetal force constraint is the principal mechanical "cost" of rotational propulsion methods. While rotation offers smoother and more controlled momentum transfer, engineering challenges arise in sustaining the necessary inward force on the payload and structural components. These factors must be carefully considered in the design and scaling of sling-based propulsion devices.

5 Controlled Recoil and Momentum Redirection

A key distinction in rotational propulsion systems is that recoil occurs primarily at the moment of release, rather than continuously throughout the acceleration phase. This characteristic enables precise control over when and how momentum is transferred. This property becomes especially powerful when combined with rotational symmetry and precise timing.

Consider the following scenario:

A circular catapult (or sling) is engineered to accelerate a small metal ball to a high tangential velocity. A second, identical catapult, positioned some distance away, rotates with the same tangential speed at the point of interception. Both catapults are designed to be significantly more massive than the projectiles they handle, ensuring that any momentum transfer causes only minimal displacement or rotation of the catapults themselves.

When the second catapult catches the incoming ball, it begins to move slightly in the direction of the ball's momentum. However, due to the large mass difference, this motion is marginal. At this point, the system has two primary options:

1. **Re-release the ball in a different direction**, causing the catapult to experience recoil opposite to the new release vector.

2. **Decelerate the ball gradually**, absorbing its momentum internally. In this case, no net recoil occurs after capture, aside from the initial momentum absorption.

If the projectile is designed to withstand the forces involved in its initial acceleration, then, by symmetry, it is naturally capable of handling the forces involved in deceleration or directional changes. This makes the entire system reversible.

Furthermore, because the catapults are much more massive than the projectiles, their reaction speeds are slower. This allows for the use of external braking or stabilization systems to control and correct any minor dislocations or drift of the catapults over time. In other words, it becomes feasible to anchor or re-center the system between transfers, maintaining spatial stability.

In summary, aside from frictional losses, such systems can transfer mass and momentum through space by leveraging a combination of angular and linear momentum control while maintaining mechanical integrity and spatial stability even across multiple transfers or changes in direction.

6 Center of Mass and System Stability

Rotational systems exhibit inherent stability when rotation is applied precisely about their combined center of mass, analogous to the balance observed in a lever or seesaw. In the initial configuration of our two-disc system, the center of mass lies slightly offset from the geometric center of disc A. However, if the rotational motion is imparted relative to the system's true center of mass (accounting for both discs) the rotation remains smooth and free from wobbling or instability.

Upon releasing one of the discs (e.g., disc B), the system's center of mass shifts almost instantly, though in practice there is a very slight delay, to the remaining mass (disc A's geometric center). This predictable shift allows the system to adapt dynamically, maintaining rotational stability throughout the process.

Understanding and managing these center of mass shifts is critical in designing rotational propulsion systems. By controlling the points of rotation and anticipating mass redistribution, it is possible to preserve system balance and prevent destabilizing oscillations during acceleration, release, and momentum transfer phases.

7 Mass Ratio and the Illusion of Recoilless Propulsion

To gain deeper insight into recoil behavior in rotational propulsion systems, consider the boundary case from the earlier thought experiment.

Disc A (the catapult) has a mass of 100 kg, while Disc B (the projectile) weighs 1 kg. When Disc B is released at a tangential velocity of 6.22 m/s, Disc A recoils in the opposite direction at approximately 0.0622 m/s, exactly 1/100th of the projectile's velocity. This inverse relationship arises from momentum conservation about the system's center of mass, which must remain stationary in the absence of external forces.

Now imagine that Disc A's mass approaches infinity. The system's center of mass would coincide exactly with Disc A's center, causing Disc A to remain effectively motionless. In this limiting case, Disc A experiences no recoil, seemingly in violation of Newton's Third Law. However, this is merely an illusion: the projectile's momentum is unchanged, but an infinite mass requires zero velocity to balance it.

Of course, infinite mass is physically impossible, and Newton's Third Law always holds. Nonetheless, this theoretical insight provides a useful design principle:

> *Increasing the mass ratio between catapult and projectile reduces recoil velocity of the catapult.*

This principle is fundamental in practical rotational propulsion design. A sufficiently massive catapult enables near-recoilless operation, enhancing stability and predictability during projectile launch or capture.

However, this advantage introduces trade-offs. Although a heavier catapult recoils less, it accumulates greater kinetic energy during any motion it undergoes. This necessitates more energy-intensive braking or stabilization, stronger structural supports, and possibly more complex control systems.

Thus, system designers must balance minimizing recoil against manageable energy costs and mechanical constraints, selecting a catapult mass large enough to reduce unwanted motion but not so large as to introduce inefficiency or complexity.

8 Conclusion

The concepts presented in this paper establish a foundation for the development of transportation and propulsion systems grounded in rotatory catapult mechanisms. These innovative approaches offer efficient, scalable, and silent alternatives to traditional technologies, with potential applications ranging from terrestrial launch platforms to advanced deep space propulsion.

While the theoretical principles of angle-linear momentum conversion are compelling, significant experimental research and engineering development remain essential to overcome practical challenges and realize these systems' full potential. The prospect of deploying such mechanisms across diverse environments and mission profiles underscores the importance of continued investigation.

Ultimately, advancing this line of research could open new frontiers in propulsion technology, enabling breakthroughs in energy efficiency, control, and versatility that reshape how we move objects through space and beyond.

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