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ARGUS-PD/POD-7K Paper II

Integrated Architecture and Feasibility Bounds for a Fixed Seven-Kilometre Electromagnetic Planetary-Defence Research System

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7,000 m fixed structure • 1,000 force cells • 6,000 module bays • rear counter-impulse

Abstract

This paper integrates the launcher, pulse-energy, structure, thermal, control, deployment and civil-governance consequences of fixing a hypothetical electromagnetic planetary-defence research system at exactly 7,000 m active length. It supersedes earlier 49 km, 98/392 km and 1,001 km architectures as system references. The common reference shot uses a **0.300 kg complete moving assembly**, not a 0.300 kg core plus additional uncounted hardware, at 1.000×10^6 m s^{-1}. The resulting 150 GJ, 14 ms and 21.429 MN mechanical requirements are exact within the constant-force model. The adopted 35% electrical efficiency and 20% installed reserve yield 428.571 GJ admitted energy and 514.286 GJ nameplate; both are assumptions pending measurement.

The paper separates three concepts previously conflated. First, 6,000 85.714 MJ “tranches” are accounting partitions, not purchasable banks. Second, an ideal 16.410 T Maxwell-pressure result over 0.200 m^2 is a force-density ceiling, not an accelerator topology. Third, a stationary 17.7 T REBCO trapped-field result is a material comparator, not evidence for a rapidly switched, metre-class launcher. Two coupling classes—switched inductive cells and a linear-synchronous superconducting interface—are therefore framed in circuit and test terms. Both require measured mutual inductance gradients, current and voltage waveforms, parasitic inductance, field penetration, losses, quench margin, stability and reaction loads.

Named terrestrial storage products do not close the combination of energy, specific power, mass, life and space qualification. The paper therefore retains a distributed hierarchy—slow solar/battery buffer, bulk pulse store, 6,000 physical fault-domain bays and local pulse-forming networks—without claiming an existing 85.714 MJ module. It also treats the proposed rear valve as an external momentum-export subsystem. The cited 1.5 m s^{-1} recoil is correct for the 3 MN s T-DART member on a 2,000 t platform; ideal cancellation at 4.5 km s^{-1} requires 666.7 kg expelled mass and does not remove structural reaction. System mass and cost remain open work-breakdown structures. The architecture advances only through evidence gates from materials and a representative cell to strings, storage, an unarmed orbital demonstrator and independently reviewed impact science. The flight environment is a separate system boundary: interplanetary dust and residual gas can create local vapour/plasma and fracture initiation. The architecture now carries a material-down-selection branch and explicit Poisson critical-hit and compound cumulative-damage requirements rather than assuming a BDD monolith will survive. An Earth-atmosphere trajectory would be a distributed ablation and energy-deposition event rather than an intact arrival. The architecture is conservation-law consistent and parametrically expressible, not engineering-demonstrated, mission-certified, costed or ready for procurement.

Keywords: electromagnetic launcher; planetary defence; pulse power; systems engineering; superconducting magnet; structural reaction; thermal management; verification.

1. Purpose, exclusions and standard of proof

The paper asks whether a fixed 7 km system can be described without violating conservation law or concealing its decisive unknowns. It does not ask whether the system can presently be built. A technically responsible result must:

- use one controlled mass and energy definition across every subsystem;
- separate ideal bounds from realisable topologies;
- distinguish catalogue comparisons from selected hardware;
- propagate changes through energy, force, area, heat, structure and recoil;
- attach each major claim to evidence or a falsifiable test; and
- exclude operational targeting, firing and command information.

The civil object is planetary defence. Terrestrial strike, anti-satellite operation, orbital combat and coercive deployment are outside the research boundary. Those exclusions do not remove the system's dual-use character; they make governance and independent safety review part of feasibility.

2. Fixed architecture and shared data dictionary

2.1 Reference shot

The system-wide inputs are:

Controlled item	Value	Epistemic status
Active length L	7,000 m	fixed study boundary
Complete moving mass m	0.300 kg	controlled reference allocation
Release speed v	1.000×10^6 m s⁻¹	theoretical study point
Coupling area A_c	0.200 m²	aggressive interface hypothesis
Electrical efficiency η_e	0.35	assumption
Installed reserve r	0.20	assumption

Controlled item	Value	Epistemic status
Accounting tranches	6,000	bookkeeping convention
Representative force cells	1,000 × 7 m	architectural partition

The complete-moving-mass identity is

$$m = m_{core} + m_{skin} + m_{load} + m_{collar} + m_{guidance} + m_{release} + m_{other}. \quad (1)$$

Paper I provides the reference allocation. Any design change that increases a moving term changes energy and force unless velocity is reduced.

2.2 Controlling arithmetic

$$E_k = \frac{1}{2} m v^2 = 150.000\, GJ,\ p = mv = 300.000\, kN\, s, \quad (2)$$

$$\acute{F} = \frac{E_k}{L} = 21.429\, MN,\ t_L = \frac{2L}{v} = 14.000\, ms. \quad (3)$$

With the declared efficiency and reserve,

$$E_{admit} = \frac{E_k}{0.35} = 428.571\, GJ,\ E_{nameplate} = 1.2\, E_{admit} = 514.286\, GJ. \quad (4)$$

The corresponding powers under constant force are:

Quantity	Value
Mean mechanical power	10.714 TW
Exit mechanical power	21.429 TW
Mean admitted power	30.612 TW
Exit admitted power	61.224 TW

These values are system duties. They do not specify how current is supplied.

2.3 Cells and accounting tranches

One thousand equal 7 m cells divide the ideal mechanical work into 150 MJ per cell. Six thousand equal energy-accounting tranches map to six tranches per cell:

Per 7 m cell	Value
Mechanical work	150.000 MJ
Expected admitted energy	428.571 MJ
Installed nameplate allocation	514.286 MJ
Accounting tranches	6 × 85.714 MJ
Nominal traversal at reference exit speed	7 μs

The mapping is useful for fault domains and energy ledgers. It is not evidence that six identical single-component stores or switches belong at every cell. It can, however, define a physical packaging hypothesis: six replaceable, fault-contained **module bays** per cell, each carrying an equal energy allocation while allowing its internal capacitor, switch, isolation and recovery assemblies to contain many components or to draw from a shared bulk reservoir. The separately deposited launcher study tests that interpretation and does not identify an existing 85.714 MJ module [15,16].

3. Force-density bound and electromagnetic topology

3.1 What the ideal field calculation proves

The ideal excluded-field relation is

$$\acute{F} = A_c \frac{B^2}{2\mu_0}. \tag{5}$$

At $A_c = 0.200$ m², Eq. (5) returns 16.410 T. At the 50 mm core area it returns about 166 T. The wide collar therefore resolves an arithmetic force-area contradiction but creates a moving-mass, aperture and release problem.

Equation (5) proves only that a uniform magnetic pressure of the stated magnitude would match mean force. It omits:

- the spatial field and current distribution;
- coupling coefficient and mutual-inductance gradient;
- field leakage and fringe forces;
- current rise, voltage and parasitic inductance;
- dynamic transverse stability;
- conductor critical surface and quench;

- eddy-current, hysteretic and dielectric losses;
- energy recovery;
- mechanical concentration and fatigue; and
- cell-to-cell timing error.

3.2 Candidate A: switched inductive travelling cells

In an inductive-cell interpretation, external coils create sequential fields that couple to a conductive or superconducting collar. A useful circuit-level force expression is

$$F_x \simeq I_s I_a \frac{dM}{dx} + \frac{1}{2} I_a^2 \frac{dL_a}{dx}. \tag{6}$$

The research variables are stator and armature currents, mutual inductance $M(x)$, armature inductance $L_a(x)$, phase timing, field penetration and loss. The attractive feature is modularity: each cell can be tested as a bounded electromagnetic and structural article. The principal risks are induced-current loss, switching voltage, timing sensitivity, asymmetric force, armature heating and poor energy recovery.

3.3 Candidate B: linear-synchronous superconducting interface

An alternative gives the moving collar a persistent or actively maintained field and drives it with an external travelling field. Force still depends on mutual-inductance gradient, but the current source, quench margin and trapped or transport-current state move into the article. REBCO trapped-field experiments provide a relevant static field comparator [1]. They do not close the rapid-slew, aperture, acceleration, radiation, fatigue or release requirements.

The expected advantages are reduced armature resistive loss and a more controllable synchronous phase. Set against them are a cryogenic state on a violently accelerated component, quench protection, and stored magnetic energy carried on the moving assembly.

3.4 Required representative-cell evidence

The first credible electromagnetic result must report:

1. geometry and materials;
2. measured current, voltage and field waveforms;
3. $M(x)$, dM/dx, self- and parasitic inductance;
4. axial and transverse force histories;
5. moving-article temperature and strain;

6. input energy, delivered kinetic energy and recoverable energy;
7. timing and position error sensitivity;
8. quench or fault response;
9. reaction-force path into the support; and
10. life over representative pulses.

Without these, neither candidate may be described as selected.

4. Pulse-energy architecture

4.1 Energy and power are separate requirements

A solar array can recharge over hours; it cannot directly supply a 14 ms shot. The architecture therefore separates:

- **slow source:** solar generation and long-duration buffer;
- **bulk pulse store:** holds the shot-scale energy;
- **local pulse-forming network:** shapes cell current and limits fault propagation; and
- **recovery path:** captures energy not transferred to the moving article.

The split is functional. No technology is assumed to satisfy all levels.

4.2 Hardware comparators

Catalogue data provide scale, not selection:

Comparator	Published duty	Literal implication for 514.286 GJ	Why it does not close
Tesla Megapack, four-hour configuration	3,916 kWh; 979 kW; up to 38.1 t	about 37 units; about 1,410 t	terrestrial; slow; not space-qualified [2]
Tesla Powerwall 3	13.5 kWh; about 130 kg	about 10,583 units; about 1,376 t	domestic product; insufficient power [3]
GA 3283CMX2640	255 kJ; about 140 kg	about 2.017 million units; about 282,000 t	pulse class but untenable mass [4]
GA PDS 35462	500 J at 100 kV	pulse shaping only	not bulk energy [5]
EMALS motor-generator report	60 MJ, 60 MW, about 36 t	many units before conversion	naval comparator, not space hardware [6]

The conclusion is not that catalogue units should be multiplied into a design. It is that no cited product closes energy, power, mass and environment. A bespoke bulk store remains an unresolved architecture dependency.

The battery-capacitor combination proposed for the architecture is functionally sound when the tiers are kept distinct. Approximately 37 four-hour Megapacks contain more than 514.286 GJ, but their combined published rating is only about 36.2 MW, compared with 30.612 TW mean admitted power for R-DART. They are therefore a scale comparator for slow buffering, not a firing source. Conversely, about 336 of the cited 255 kJ CMX units would fill one 85.714 MJ equal allocation, at roughly 47 t before buswork and protection. This makes a physical 6,000-bay architecture conceivable while leaving the energy-bearing contents unclosed. Sandia's repeated Marx and intermediate-store chains similarly show that a pulse-power "module" can contain many capacitors and switches; their facility does not close the POD-7K scale [15].

4.3 Storage acceptance model

For any candidate storage system, the paper requires:

$$m_{store} \geq max\left(\frac{E_{nameplate}}{\epsilon_E}, \frac{P_{required}}{\epsilon_P}\right), \tag{7}$$

where ϵ_E is installed usable specific energy and ϵ_P installed usable specific pulse power. The plus sign is not appropriate: energy and power may constrain the same hardware, so the greater lower bound governs before adding switches, conductors, containment, thermal control and redundancy. Both specific metrics must be demonstrated at relevant duty and life.

4.4 Efficiency and waste heat

At 35% efficiency, 278.571 GJ per reference shot does not become moving kinetic energy. Some fraction may be recovered; the remainder becomes heat, electromagnetic radiation, vibration or switching loss. If net unrecovered waste is E_w and the interval between shots is T_c,

$$\acute{P}_{reject} = \frac{E_w}{T_c}. \tag{8}$$

For the intentionally conservative no-recovery case, one shot per day implies 3.224 MW average rejection. This is a cadence-level thermal load, not the local millisecond temperature rise in coils, switches and collar. Both must close.

5. Structure, reaction and alignment

5.1 Reaction, launch-period displacement and rear counter-impulse

The moving assembly receives 300 kN s momentum. The launcher receives equal and opposite impulse. Opposed electromagnetic fields can centre loads or reduce selected bending moments; they cannot remove net momentum.

For free platform mass M_p,

$$\Delta v_p = \frac{m v}{M_p}. \quad (9)$$

A 30 t platform would change velocity by 10 m s^{-1} absent external impulse or counter-mass, which alone disproves the earlier 30 t total-system claim as a credible reference. A 300,000 t platform would still experience 1 mm s^{-1}.

The proposed rear valve is a valid **external counter-impulse** if it expels reaction mass. For projectile impulse J_p, expelled mass m_e and effective exhaust velocity u_e,

$$J_c = m_e u_e, \Delta v_{res} = \frac{J_p - J_c}{M_p}. \quad (10)$$

If $J_c = J_p$ and the impulse vectors are collinear, the ideal final platform translation is zero. Momentum is carried away by the projectile and exhaust; it is not erased. The launcher still carries distributed reaction and the opposed rear force creates an axial structural load.

The proposed 1.5 result closes precisely for the 3 MN s T-DART member and a 2,000 t free platform: $\Delta v_p = 1.5$ m s^{-1}. Its 140 ms constant-force launch produces about 0.105 m ideal displacement before any post-shot drift. Exact counter-impulse at 4.5 km s^{-1} would require 666.7 kg of expelled mass. The R-DART reference on the same platform gives 0.15 m s^{-1}, 1.05 mm launch-period displacement and 66.7 kg ideal expelled mass. These centre-of-mass results do not specify a valve, propellant, pressure vessel, plume-safe direction or timing controller [16].

5.2 Distributed force and modal response

Mean axial force is only the zero-frequency component of the structural load. Each cell produces a transient reaction with spatial and temporal harmonics. The structure requires:

- a global axial and bending load path;

- local coil and cryostat restraint;
- modal separation from pulse-train harmonics;
- metrology of the instantaneous magnetic centreline;
- thermal-distortion control;
- fault-load cases for a missing, early or asymmetric pulse; and
- ring-down criteria before another shot.

A quasi-static average cannot certify these conditions. Representative-cell and string tests must feed a validated transient finite-element model.

5.3 Pointing hierarchy

Three functions are separated:

1. **platform orientation:** slow movement of the whole installation;
2. **structural alignment:** metrology and trim of the 7 km centreline; and
3. **release-state correction:** bounded adjustment of the moving assembly before separation.

An in-bore large-angle turn at extreme velocity is rejected as a reference mechanism because transverse force and clearance would dominate. Platform orientation must be substantially complete before arming. The papers do not publish aim envelopes or target solutions.

6. Moving assembly, release and guidance interface

Paper I owns material and moving-mass selection. The system interface must transfer the reference force from a 0.200 m^2 electromagnetic collar into a much narrower structural article while preserving:

- centre-of-mass and centre-of-force alignment;
- conductor and dielectric integrity;
- a known release time and attitude covariance;
- controlled collar separation or retention;
- safe fragments and passivation after an abort; and
- telemetry sufficient to reconstruct a test.

The 0.300 kg allocation includes collar and release hardware until separation. The mass ledger is a hard constraint, not a note below a table.

7. Thermal, cryogenic and environmental constraints

7.1 Thermal hierarchy

The thermal model must distinguish:

- local adiabatic pulse heating;
- cell-to-cell conductive spreading;
- cryogenic recovery;
- average radiator duty;
- solar and planetary heat input; and
- degraded-operation and safe-state loads.

For a radiator at effective temperature T, emissivity ϵ_r and sink temperature T_s,

$$P_{rad} = \epsilon_r \sigma A_r \left(T^4 - T_s^4 \right). \tag{11}$$

Equation (11) provides an area lower bound but omits view factors, degradation, two-sided geometry, fluid loops and shadowing.

7.2 Cryogenic architecture

REBCO can reduce some resistive losses but creates refrigeration and quench requirements. The paper does not assume all 7 km remains at one uniform temperature. A plausible research architecture uses thermally isolated cell modules, local protection and a warm structural spine. The acceptance evidence is measured heat leak, cryocooler input, recovery time and fault propagation, not a generic claim that space is cold.

7.3 Radiation, dust and debris

A long structure presents a large cross-section to micrometeoroids and debris. Its fault model requires segmentation, isolation, inspection, bypass, replaceable modules and safe degradation. A one-cell failure must not create a high-energy asynchronous event in adjacent cells.

The released projectile has a different environmental problem. NASA's Meteoroid Engineering Model 3 resolves hazardous flux by grain mass, direction, speed and density [17]. At 1,000 km s^{-1}, even a 1 µg dust grain has 500 J of local collision energy. Hypervelocity impact research supports crater, vapour and plasma formation [18], but not intact flight of a macroscopic boron-doped-diamond article at the ARGUS speed range. The projectile verification programme must derive a critical-grain threshold from tests and fracture simulation, integrate the corresponding flux along the trajectory, and include residual-gas, charge and cumulative erosion.

This is not a single-material verification branch. Paper I compares CVD diamond, BDD, diamond-SiC, toughened SiC, boron carbide, tungsten and carbon-rich sacrificial layers [21]. CVD-diamond fracture tests and more recent microcrystalline/nanocrystalline measurements show why toughness, modulus, residual stress and flaw population must be tied to a specified microstructure [24,25]. A diamond-SiC study reports strong microscale interfaces but not whole-article hypervelocity survival [26]. The system architecture must preserve interchangeable coupon and nose configurations until matched high-rate evidence selects one.

The adjacent Solar Probe Plus/Parker Solar Probe shield literature provides a configuration-specific 7-150 km s^{-1} ballistic-limit workflow [22], while relativistic-probe studies treat crater, melt and cumulative erosion from dust and gas [23]. Their numerical ballistic limits are not transferable to ARGUS, but their combination of environmental fluence, material-specific damage, hydrocodes and tests is.

For an already-defined critical population, a uniform sensitivity screen over path D is

$$\lambda = A_p n_{\geq m_*} D, P(N \geq k) = 1 - e^{-\lambda} \sum_{j=0}^{k-1} \frac{\lambda^j}{j!}. \tag{11a}$$

For a 50 mm projected diameter, 50% probability of at least one critical hit corresponds to uniform critical-particle densities 3.53×10^{-4}, 3.53×10^{-7} and 2.36×10^{-9} m^{-3} over 1,000 km, 1,000,000 km and 1 au. These are threshold sensitivities, not estimates of space-dust density. Trajectory-specific particle distributions must be transformed into the projectile frame. Repeated subcritical impacts require a calibrated compound damage model for crater overlap, erosion, charge, angular impulse and crack coalescence; choosing an arbitrary integer k is insufficient.

Boron concentration is also a controlled material input. Highly doped single-crystal diamond can have reduced elastic properties and hardness relative to pure diamond [19]. Structural allowables may not be borrowed from undoped material simply because a BDD surface is desired for electrical function.

Earth-atmosphere passage is excluded as an intact-projectile mode. The atmospheric column is approximately 1.03×10^4 kg m^{-2}; even a 50 mm circular core cross-section intersects about 20.3 kg. At the declared speeds, ablation, dissociation, ionisation, radiation, plasma and fragmentation require nonequilibrium radiation-hydrodynamics [20]. A quoted surface impact is not an acceptable environmental assumption.

8. Renewable operation and lifecycle claims

Solar charging can make post-deployment operations renewable in the narrow electricity-accounting sense. At 10 MW net charging power, the ideal time to replace 428.571 GJ is 11.9 h; actual time is longer after storage and housekeeping losses.

The phrase *completely green* is withdrawn. Diamond growth, boron and REBCO production, conductor and composite manufacture, launch, replacement and end-of-life have material and emission burdens. A stronger environmental claim requires an ISO-aligned life-cycle inventory with declared system boundary, energy source, allocation and uncertainty [7,8].

9. Deployment, system mass and cost discipline

9.1 Work-breakdown mass model

No total installed mass is reported as an estimate. The deposit package instead supplies this required work breakdown:

WBS element	Required estimating basis
Moving assemblies	member-specific Eq. (1) mass ledger
Force cells	measured representative-cell mass per metre
Bulk storage	demonstrated usable specific energy and power
Pulse forming and switching	cell-level hardware and redundancy
Structure and reaction system	transient load model and margin
Thermal/cryogenic system	heat loads and demonstrated coefficients of performance
Solar generation and buffer	mission orbit, degradation and recharge cadence
Metrology, control and communications	equipment list and redundancy
Deployment and logistics	packaging, launch manifest and assembly sequence
Spares and disposal	reliability model and end-of-life plan

A claimed total is acceptable only when every row has a source, maturity, uncertainty range and contingency rule. The work-breakdown, requirement allocation, verification and decision-gate structure follows established systems-engineering practice [14].

9.2 Cost model

The same discipline applies to cost. There is no defensible point estimate while representative hardware is absent. A future parametric estimate shall include design, qualification, flight hardware, launch, assembly, facilities, operations, reserves and decommissioning. Historical programmes may inform cost classes, but they are not scalar analogies for an unbuilt 7 km pulse-power system.

9.3 Deployment sequence

The research sequence is modular:

1. qualify materials and interfaces on Earth;
2. qualify a representative electromagnetic cell and store;
3. test physical strings and timing;
4. demonstrate deployment and metrology with no high-energy payload;
5. operate an unarmed low-energy orbital demonstrator;
6. complete independent safety, legal and environmental review; and
7. consider any higher-energy civil demonstration only after prior gates.

The sequence does not imply a schedule. Each gate can terminate the programme.

10. Civil governance and dual-use constraints

The Outer Space Treaty makes States Parties internationally responsible for national space activities and requires authorisation and continuing supervision of non-governmental activities [9]. Registration, liability, due regard, consultation and long-term sustainability add further obligations and expectations [9-13]. Those instruments do not transform a theoretical paper into an authorised activity.

Any future programme would require, at minimum:

- independent confirmation of a natural hazard;
- target-specific civil authorisation;
- registration and continuing supervision;
- multi-party physical release authority;
- observable Earth-avoidance and passivation logic;
- independent tracking and public incident reporting;
- liability and insurance arrangements;
- export-control and information-security review; and

- end-of-life and debris plans.

The companion legal paper treats these questions separately. This engineering paper uses them as design constraints, not legal conclusions.

11. Verification programme and decision gates

Gate	System question	Evidence required	Decision
A	Does the moving mass close?	weighed core/skin/load/collar/release prototype	revise mass and all dependent arithmetic if not
B	Can one topology transfer representative force density?	measured cell force, waveform, efficiency, loss and stability	select, redesign or stop
C	Can a physical string synchronise safely?	multi-cell timing, fault isolation and structural transient	scale only if validated
D	Can storage meet energy and pulse duty?	module specific energy/power, life, containment and recovery	reduce shot or stop if deployment fails
E	Can a long inert structure deploy and align?	unarmed orbital metrology and control demonstration	no energetic testing without success
F	Does release remain bounded?	subscale accelerated assembly and separation covariance	redesign interface if uncontrolled
G	Does the projectile survive its flight environment?	matched material tests, particle-frame fluence, Poisson critical-hit and compound cumulative-damage probability	no high-speed flight claim without survival envelope
H	Is impact effect predictable?	independently validated impact experiments and models	no mission claim without envelope
I	Is a target-specific civil mission safe and lawful?	independent scientific, safety and legal authorisation	mission-specific decision only

12. Integrated adjudication

Proposition	Result
150 GJ/7 km arithmetic	established within the model
0.300 kg moving-mass closure	explicit study allocation; unvalidated
0.200 m², 16.410 T ideal screen	arithmetically established; not topology
6,000 tranches	valid accounting; may map to 6,000 module bays, but contents unvalidated

Proposition	Result
present storage closes	not established
representative coupling cell exists	not established
rear counter-impulse principle	conservation-law valid; hardware and structural closure not established
structure and residual recoil close	not established
renewable post-deployment operation	parametrically possible; unvalidated
pollution-free lifecycle	withdrawn
installed mass and cost	not estimated
mission viability	target-specific and not established

The architecture is therefore conservation-law consistent and parametrically expressible. The decisive unknown is not a special physical prohibition but whether representative hardware can close mass, pulse, coupling, stability, life, thermal and deployment requirements at the same time. The system shall not be described as engineering viable before that evidence exists.

13. Conclusion

Fixing the active length at 7 km makes the concept testable because it prevents earlier length changes from hiding force and power. It also exposes the severity of the design: 21.429 MN mean force, a 14 ms launch, tens of terawatts admitted during the pulse, a wide moving interface and substantial reaction impulse.

The strongest result is an auditable chain of dependencies. The strongest negative result is that named present hardware does not close the combined energy-power-mass envelope. The most important correction is that the collar, guidance and release hardware belong inside the 0.300 kg moving mass. The most important next experiment is a representative coupling cell with a weighed moving article and a complete energy, force, stability, loss and reaction ledger.

Declarations

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Competing interests. The author declares no competing financial interest.

Data and code availability. Controlled constants, reference calculations, mass ledger, design grid, unit tests, figures and machine-readable tables accompany the publication. No mission-grade trajectory, targeting, electromagnetic finite-element, quench, structural or impact-hydrodynamics model is represented as available.

Dual-use boundary. Operational target data, firing sequences, live command architecture and aim envelopes are excluded.

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