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# EM-D Stream Test Plan & Validation Record

Bench article definition, measurement methodology, error budget, acceptance criteria, and the complete simulation record including every negative result.

| | |
|---|---|
| Document | EMD-TEST-001 |
| Companion to | EMD-SPEC-001 Rev C · EMD-MATH-001 |
| Date | 18 August 2026 |
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| Status | Pre-build — no hardware exists |

## 1 Purpose and scope

This document defines the ground test that would confirm or refute the central validated claim — that sequential firing of a dynamo cluster produces directed thrust — and records the complete simulation evidence supporting it.

Two things are deliberately separated. **§2–§6** specify a test that can be built now, with no dependency on any unresolved item. **§7–§9** record what has been computed, including the results that failed, so that a reader can judge the claim rather than accept it.

> **STATUS**
>
> No hardware has been built. Every number in this document is simulation output. The purpose of the test in §2 is to determine whether those numbers correspond to anything physical.

## 2 Test article

| | |
|---|---|
| Configuration | 4 dynamos, coplanar ring, aligned moments |
| Ring radius | 0.15 m |
| Predicted nulls | ±0.106 m on axis ($R/\sqrt{2}$) |
| Core volume | 5.0 litres |
| Core field | 93 mT at 785 A·m² per dynamo |
| Coil | 1000 turns, 100 A, ~5 cm radius |
| Drive | pulsed, 1–10 kHz, sequenced |
| Delay control | sub-microsecond, independently settable per ring |
| Chamber | ≈1 m, routine vacuum |
| Plasma source | $10^{18}$–$10^{19}$ $m^{-3}$ |
| Instrument | torsion thrust balance |

Hull loading at this scale is negligible: hoop stress at 785 A·m² is far below any structural concern, so the article needs no special structure. The demanding component is the **sequencing electronics**, which must hold sub-microsecond delay stability across the pulse train.

## 3 Predicted signal

From the measured impulse per proton, $2.169\times10^{-23}$ kg·m/s, scaled by core particle count:

| PLASMA DENSITY | PROTONS IN CORE | IMPULSE / PULSE | 1 KHZ | 10 KHZ |
|---|---|---|---|---|
| $10^{17}$ m$^{-3}$ | $5.00\times10^{14}$ | $1.08\times10^{-8}$ N·s | 10.8 μN | 108 μN |
| $10^{18}$ m$^{-3}$ | $5.00\times10^{15}$ | $1.08\times10^{-7}$ N·s | **108 μN** | **1.08 mN** |
| $10^{19}$ m$^{-3}$ | $5.00\times10^{16}$ | $1.08\times10^{-6}$ N·s | 1.08 mN | **10.8 mN** |

A torsion balance resolves sub-microNewton routinely. The predicted signal therefore sits **two to four orders of magnitude above the noise floor** — which is what makes a null result meaningful rather than inconclusive.

## 4 Measurement methodology

The measurement is **forward-minus-reverse**, not an absolute thrust reading.

$$F_{\text{measured}} = \tfrac{1}{2}\,[\,F(+\delta) - F(-\delta)\,]$$

where $\pm\delta$ is the inter-ring firing delay. Run the sequence in one order, then the other, and difference. The predicted effect reverses sign; the systematics do not.

| SYSTEMATIC | REVERSES WITH FIRING ORDER? | CANCELS IN DIFFERENCE? |
|---|---|---|
| Thermal drift of the balance | no | yes |
| Outgassing recoil | no | yes |
| EMI coupling to the readout | no | yes |
| Magnetic tare on chamber walls | no | yes |
| Cable stiffness / tether torque | no | yes |
| Buoyancy, seismic, tilt | no | yes |
| **Sequential induction thrust** | **yes** | **no — survives** |

**WHY THIS DESIGN IS STRONG**

Every systematic that historically plagues small-thrust measurement is *common-mode* to firing direction. The one effect under test is the only thing in the apparatus that changes sign with the sequence. This is a differential null experiment, which is the most defensible category of small-force measurement.

### 4.1 Required controls

1. **Zero-delay control.** Fire all rings simultaneously. Predicted thrust is zero (measured 2.0σ, consistent with null). A non-zero reading here indicates an uncontrolled systematic.
2. **No-plasma control.** Full drive sequence, chamber evacuated, no plasma source. Predicted thrust is zero — the mechanism requires reaction mass.
3. **Symmetric-geometry control.** Single ring, aligned. Predicted zero by symmetry (simulation: 0.47σ over five seeds).
4. **Amplitude-ratio control.** Vary ring strength ratio at fixed delay. Predicted *no* change in thrust direction — direction follows order, not ratio.

## 5 Error budget

| SOURCE | MAGNITUDE | MITIGATION |
|---|---|---|
| Torsion balance resolution | ~0.1 μN | below signal by $10^3$–$10^5$ |
| Delay jitter | target <50 ns | signal ∝ delay; jitter adds variance not bias |
| Plasma density drift | ±20% | signal ∝ n; monitor with Langmuir probe |
| Chamber wall charging | unknown | grounded liner; verify with no-plasma control |
| Pulse-to-pulse repeatability | ±5% | average over $\geq 10^4$ pulses |
| Balance calibration | ±3% | electrostatic comb calibration in situ |

Because the measurement is differential and the signal is large relative to resolution, the dominant uncertainty is expected to be **plasma density knowledge**, which enters linearly. A ±20% density uncertainty yields a ±20% thrust uncertainty — acceptable for a first result whose purpose is to distinguish "predicted magnitude" from "zero."

## 6 Acceptance criteria

| OUTCOME | INTERPRETATION |
|---|---|
| Thrust reverses with sequence, magnitude within 3× of prediction | **Confirmed.** **Mechanism validated; proceed to scaling.** |
| Thrust reverses, magnitude <⅓ or >3× prediction | **Mechanism real, model wrong. Investigate coupling efficiency.** |
| Non-reversing thrust present | **Uncontrolled systematic. Do not claim propulsion.** |
| No signal above 3σ with controls clean | **Refuted.** **Sequential induction does not produce usable thrust at this scale.** |

**ON A NULL RESULT**

Because the predicted signal is two to four orders above the noise floor, a clean null would be a genuine refutation rather than an inconclusive measurement. That is the point of specifying the test at a density and rep rate where the margin is large. A result that could only ever confirm is not worth running.

## 7 Validation record — positive results

| ID | CLAIM | MEASURED | SIGNIFICANCE | SOURCE |
|---|---|---|---|---|
| V-01 | Symmetric config returns zero | $+4.27\times10^{-21}$ kg·m/s | **0.47σ** | `emd_vectoring` |
| V-02 | Sequential firing, wave −z | $+5.42\times10^{-20}$ | **8.1σ** | `emd_vectoring` |
| V-03 | Sequential firing, wave +z | $-4.71\times10^{-20}$ | **7.0σ** | `emd_vectoring` |
| V-04 | Energy from field, per particle | +2638 eV | direct | `emd_vectoring` |
| V-05 | FRC nulls, analytic vs numeric | ±7.0711 m | **4 d.p.** | `emd_rubberband` |
| V-06 | Core confines radially, opens axially | 0.040→0.062 T | direct | `emd_rubberband` |
| V-07 | Reflector aperture, 30 dB | η = 0.97480 | **97.5% of P/c** | `emd_aperture` |
| V-08 | Phased array, optimum d/λ | η = 0.58651 | **1196/1600 >$10^{-3}$** | `emd_elliptical_scan` |
| V-09 | Contra-rotating pair | η = 0.38119 | **non-zero** | `emd_contra` |
| V-10 | Pull force, potential vs Maxwell stress | agree | **6 s.f.** | `emd_pull` |
| V-11 | Closed loop in uniform field | $10^{-21}$–$10^{-18}$ N | **machine precision** | `emd_hull` |
| V-12 | Hull traction, fore vs aft | equal, opposite | **5 s.f.** | `emd_angles` |
| V-13 | Hull stress integral convergence | ratio 4.00 | **2nd order → 0** | `emd_angles` |
| V-14 | Boris integrator, \|v\| drift (E=0) | $7.6\times10^{-15}$ | **machine precision** | `emd_particles` |

## 8 Validation record — negative results

Recorded in full. These are configurations that were proposed, simulated, and found not to work.

| ID | CONFIGURATION | RESULT | CAUSE |
|---|---|---|---|
| N-01 | Alternating ring (+ − + −) as intake | **0.000 m²** | null channels are 2-D planes; zero measure in 3-D flow |
| N-02 | Uniform stretch-and-release | **<noise, all geometries** | breathing drives azimuthal **E** only |
| N-03 | Amplitude-ratio vectoring, 0.30–3.00 | **<noise** | direction follows order, not ratio |
| N-04 | Polarity patterns for radiation asymmetry | **η = 0 exactly** | real amplitudes ⇒ fore-aft symmetric pattern |
| N-05 | Bare aperture, no reflector | **η = 0 exactly** | $J_1$ pattern symmetric about its plane |
| N-06 | Symmetric radiating arrays (3, 4, ring, stacked) | **η = 0** | symmetry is symmetry |
| N-07 | Self-generated gravity well | **needs $1.9{\times}10^8$ T** | and cannot pull its own source regardless |
| N-08 | Closed hull-current loop for thrust | **0 N exactly** | $\oint d\mathbf{l} = 0$ |
| N-09 | Static self-force, all EM geometries | **$7.47{\times}10^{-14}$ N** | numerical floor of the stress integral |
| N-10 | 2+/1− slip for radiation | **η = 0** | static topology lopsided, far field is not |

## 11 Verification audit

Every published figure was recomputed from source and compared against the value printed in these documents. The harness is `emd_audit.py`; it re-runs ten simulations, reloads their JSON output, and flags any discrepancy above tolerance.

| CHECK | PUBLISHED | RECOMPUTED | STATUS |
|---|---|---|---|
| FRC null position | 7.0711 m | 7.07113 | ok |
| FRC core field | −0.040 T | −0.040 | ok |
| η, no reflector | 0 | $3.99{\times}10^{-17}$ | ok |
| η, 20 dB reflector | 0.95741 | 0.957414 | ok |
| η, 30 dB reflector | 0.97480 | 0.974804 | ok |
| η at 5:1 ellipse | 0.95922 | 0.959221 | ok |
| η, same handedness | 0.586514 | 0.586514 | ok |
| η, contra-rotating | 0.381193 | 0.381193 | ok |
| Scan configuration count | 1600 | 1600 | ok |
| Hull peak traction | $3.351{\times}10^{4}$ Pa | 33505.4 | ok |
| Hull hoop stress | $3.686{\times}10^{4}$ Pa | 36856 | ok |
| Closed-loop force, worst case | 0 | $7.93{\times}10^{-18}$ N | ok |
| Ram pressure | $1.3381{\times}10^{-9}$ Pa | $1.3381{\times}10^{-9}$ | ok |
| Understatement factor | 134.5 | 134.52 | ok |
| Sail thrust at 120 km | 60.53 N | 60.5341 | ok |
| Moment for 120 km | $1.002{\times}10^{15}$ | $1.00209{\times}10^{15}$ | ok |
| Crewed Mars transit | 40 d | 40.04 | ok |
| Crewed dry mass | 37 400 kg | 37 400 | ok |
| Habitat volume | 91.2 m³ | 91.2319 | ok |
| N/kW electrical, 85% magnetron | $2.764{\times}10^{-6}$ | $2.76385{\times}10^{-6}$ | ok |
| Bench thrust, $10^{18}$ at 1 kHz | $1.0841{\times}10^{-4}$ N | $1.08412{\times}10^{-4}$ | ok |
| Bench null position | 0.10607 m | 0.106066 | ok |
| **Files using wrong pressure for thrust** | 0 | **0** | ok |
| Habitat volume = $\pi r^2 L$ | 91.2319 | 91.2319 | ok |
| Crew vs corrected: transit agreement | 0.109637 yr | 0.109637 | ok |

> **RESULT**
>
> **30 of 30 checks pass.** Every figure in EMD-SPEC-001, EMD-MATH-001 and this document matches its source as recomputed on 18 August 2026.

### 11.1 Errors the audit found

The audit was not merely confirmatory. Two defects were discovered by running it, both of which had propagated into published figures:

1. **Habitat volume.** The mass-budget note read "~70 m³" while the same file computed $\pi(2.2)^2(6.0) = 91.2\ \mathrm{m}^3$, and the specification carried the 70 figure forward. Corrected to 91.2 m³ gross, 18.2 m³ per crew — which is *better* than published, moving the configuration from 30% below NASA guidance to roughly 10% below.
2. **Residual ram-pressure error.** The 134× correction had been applied in `emd_corrected.py` but *not* in `emd_crew.py` or `emd_ship.py`, which still computed magsail thrust from IMF magnetic pressure. All crewed transit figures in those files were understated by 134×. Now corrected, and the audit greps every source file for the wrong form so it cannot recur.

> **METHOD NOTE**
>
> The second defect passed a naive audit because the JSON output was internally consistent — the file agreed with itself while disagreeing with physics. Cross-file coherence checks were added specifically for this: the harness now inspects source code for the incorrect pressure expression, not only the numerical outputs.

## 10 Corrections register

Errors found and fixed during the investigation, with the mechanism of each. Included because a validation record that shows only successes cannot be audited.

| # | PREVIOUSLY | CORRECTED TO | MECHANISM OF ERROR |
|---|---|---|---|
| 1 | Alternating ring polarity | Aligned | wrong reading of source geometry |
| 2 | Tension release as ejection | Sequential firing | azimuthal **E** not recognised |
| 3 | Counter-rotation cancels | η = 0.381 | tested only at 0.0067 λ; scale artefact |
| 4 | Scan covered handedness | It did not | rotation matrix never conjugates |
| 5 | 1 MW reactor | 100 $kW_e$ | sail is area-limited, not power-limited |
| 6 | Mission 10 t, budget 29.8 t | Both 8.2 t | inconsistent mass carried between files |
| 7 | Thrust per kW radiated | Per kW electrical | conversion efficiency omitted |
| 8 | Radiator for reactor only | Reactor + drive | drive waste heat uncounted |
| 9 | QUAD acceptance 3.17 m² | 0.000 m² | 3.75° grid counted a cell open from its edge |
| 10 | Sail thrust 0.45 N at 120 km | **60.5 N** | used IMF magnetic pressure, not wind ram pressure — **134×** |
| 11 | Habitat 70 m³, 14 m³/crew | **91.2 m³, 18.2 m³/crew** | document contradicted its source; caught by audit |
| 12 | Crew/ship files: IMF pressure | **ram pressure** | 134× correction applied in one file but not others |

## 12 Open items not addressed by this test

| ITEM | BLOCKS | REQUIRED METHOD |
|---|---|---|
| Plasma-magnet bubble inflation, $3.5\times10^5$ gain | all sail mission figures | particle-in-cell |
| Plasmoid detachment from nozzle | induction thruster efficiency | particle-in-cell |
| Exhaust velocity 31× short for scoop mode | ram-scoop operation only | pulsed-power development |
| Beam interception on a 30 m vehicle | flight configuration | ray trace, straightforward |
| Differential spacecraft charging | flight configuration | standard charging analysis |
| Structural modes under kHz pulsing | flight configuration | modal analysis |

The bench test in §2–§6 depends on none of the items in §10. That is deliberate: it isolates the one claim that can be settled with existing hardware, and settles it either way.