Multistaged Ducted (MSD) EAD Thruster — Build Specification

Project: EAD Propulsion, Phase 2
Reference: Gomez Vega, N. (2023). *Advances in electroaerodynamic thrusters for aircraft propulsion.* PhD thesis, MIT AeroAstro — Chapter 4 (MSD theory), Chapter 5 (10-stage experiments, Fig. 5-2 hardware).
Prerequisite: Completed Phase 1 single-stage thruster with clean I–V and thrust data. Do not start here.
Benchmark to beat: The thesis's 10-stage device produced **0.84 N static thrust** over a 0.0324 m² cross-section — **26 N/m² at 5.0 N/kW**, >7× the static thrust density of the electrodes that flew MIT's 2018 airplane. That is the current experimental state of the art for this architecture, built with foam, wood, foil, and 3D prints. It is genuinely reproducible in a garage, minus the lab-grade power supply.

---

1. Concept

Stack N corona-discharge stages in series inside a duct fitted with a smooth inlet and a nozzle. Each stage adds a pressure rise (like compressor stages); the duct itself contributes thrust like a ducted fan shroud. Thrust grows roughly linearly with stage count at first — the thesis measured 5.6× thrust at 10 stages vs 1 — with diminishing returns as internal flow velocity (and thus pressure loss) rises.

The clever electrical trick that makes 10 stages practical with **one** power supply: **alternating polarity**. Stage 1's emitters connect to HV(+) and to stage 2's *collectors*; stage 1's collectors connect to ground and to stage 2's *emitters*. Odd stages run positive coronas, even stages run negative coronas, and the whole stack needs only one supply and one voltage.

2. Design Parameters (from the thesis 10-stage article)

Parameter	Thesis value	Your build
Stage duct	180 × 180 mm internal square, 51 mm tall, modular	Same — one printed/foam module per stage

Parameter	Thesis value	Your build
Stage count	1–10 tested	Build 10 modules; test at 1, 2, 4, 6, 8, 10
Electrode pairs per stage	9, spacing Δ = 20 mm	Same
Emitter	56 μm tungsten wire	Same as Phase 1
Collector	Wooden flat plate + foil, 10 mm chord, 1.1 mm thick	Same (flat plates chosen over airfoils purely for manufacturing speed; airfoils reduce losses — see §7)
Gap: positive (odd) stages	d = 20 mm	Same
Gap: negative (even) stages	d = 25 mm	Same — negative coronas spark at lower voltage, so they get a bigger gap to equalize

Parameter	Thesis value	Your build
		spark limits across the stack
Inter-stage distance θ (emitter to previous collector TE)	~19 mm	Same
Inlet	Parabolic, 80 mm long, 35 mm wide, 15 mm thick, 15 mm rounded lip	Same — foam, sanded smooth
Nozzle	Straight, 100 mm long; area ratios φ = 1.0 / 0.8 / 0.6 / 0.4	Build φ = 1.0 first (**converging nozzles reduced static thrust** in the thesis; they only help with forward speed)
Assembly	Two nylon M8 threaded rods clamp stages	Same

Parameter	Thesis value	Your build
	between nuts	
Voltage	Up to 18 kV	Same, single positive supply
Total current, 10 stages	Few mA	Supply: 0–20 kV, ≥ 5 mA, current-limited

3. Bill of Materials (beyond Phase 1)

- 10× stage modules: foam board walls (180 mm internal square × 51 mm tall) or a 3D-printed frame per stage. Design once, replicate.
- 2× nylon M8 threaded rods, ~700 mm, plus nylon nuts/washers — the structural spine
- Basswood or thin plywood strips, 10 mm × 1.1 mm — flat-plate collectors (9 per stage × 10 stages = 90), foil-wrapped
- Acrylic strips — external emitter holders (thesis: emitters externally mounted, collectors in internal slotted wooden holders)
- Aluminum foil, copper tape (inter-stage electrical jumpers), electrical tape
- One collector holder per stage gets a foil-faced side against the duct wall — that's the stage's

collector bus (thesis method)

- HV supply upgrade: the stack draws roughly N× single-stage current at the same voltage. Thesis used a 12 mA-class positive supply. 0–20 kV at 5 mA minimum, adjustable, metered, current-limited.
- Everything from Phase 1: ballast chain, grounding stick, HV lead, scale + hanging frame, hygrometer.

4. Construction Sequence

Step 1 — Prototype one module. One stage, 9 pairs, flat-plate collectors, exactly per the table. Bench-test it alone (it's just a Phase 1 variant with cheaper collectors). Fix problems now, then replicate ×10. Modularity is the whole game: every stage identical except gap spacing (20 mm odd / 25 mm even — make two holder variants).

Step 2 — Replicate. Build the remaining 9 modules. Consistency beats craftsmanship: identical gap, identical Δ, identical wire tension. A stack is only as good as its sloppiest stage.

Step 3 — Inlet and nozzle. Hot-wire or sand a parabolic inlet lip (80 mm long, 15 mm rounded leading edge) from foam. Make a straight φ = 1.0 exit duct 100 mm long. (Optionally make φ = 0.8/0.6/0.4

nozzles later for the forward-flight research question — at static conditions they *lose* thrust.)

Step 4 — Stack and clamp. Thread the rods through the module ears, alternate 20/25 mm stages (positive first), clamp with nuts. Small inter-stage gaps from surface imperfections are tolerable (the thesis had them) but minimize with foam tape gaskets.

Step 5 — Alternating-polarity wiring. With copper-tape jumpers at each stage joint:

- Stage 1 emitters ← HV(+); Stage 1 collectors ← ground
- Stage 2 collectors ← HV(+) (jumped from Stage 1 emitters); Stage 2 emitters ← ground (jumped from Stage 1 collectors)
- Repeat the pattern up the stack. Every jumper taped smooth — inter-stage joints are the prime spot for spurious external coronas.

Step 6 — Thrust stand. Same hanging-balance arrangement as Phase 1, thruster vertical, inlet up, exhaust down, scale well clear of HV.

5. Test Plan

1. **Stage-count sweep.** Run identical voltage sweeps at 1, 2, 4, 6, 8, 10 stages. Plot thrust vs N. Expect near-linear growth flattening toward 10 (thesis:

5.6× at $N = 10$, $\varphi = 1.0$). Sub-linear early growth = a weak stage or leakage; find it with a dark-room glow inspection.

2. **Voltage sweep at N = 10.** Thrust density vs V up to ~18 kV. Target zone: **10–26 N/m²** (0.32–0.84 N). Anything above ~15 N/m² puts you above every published single-stage device.
3. **Acoustics.** A healthy stack at these voltages should be near-silent. Crackle = reverse emission or tracking; dark-room inspect stage by stage.
4. **Optional — nozzle study.** Repeat at φ = 0.8/0.6/0.4 and confirm the counterintuitive thesis result (static thrust *drops* with converging nozzles). This is a real, publishable-quality replication exercise.

Data to keep: V, I, thrust, N stages, φ, RH, T, per-run notes on any visible/audible discharge anomalies.

6. Safety — everything from Phase 1, plus

- **More stored energy, more current.** A 10-stage stack at 5 mA is a substantially nastier shock source than the single stage. The one-hand rule and grounding-stick discipline are now non-negotiable habits, not suggestions.

- **Mid-stack potentials.** With alternating polarity, *internal* buses sit at full rail even though every stage sees the same ΔV. Treat every jumper and both rods' vicinity as live. Bleed the stack at multiple points before touching.
- **Ozone scales with stages.** Ten stages make roughly ten stages' worth of ozone. Outdoor or high-ventilation operation strongly preferred for long runs.
- **Nylon hardware only** through the stack — no metal rods/screws in the field region.

7. Upgrade Path (thesis "future work," in build order)

1. **Airfoil collectors.** Swap flat plates for small printed airfoils to cut the loss coefficient — the thesis flags this as the first improvement, with an optimum chord (smaller chord = less drag but weaker corona).
2. **Smaller gaps.** The data says volumetric performance keeps improving below 15 mm; the obstacle is manufacturing precision, which is a solvable 3D-printing problem.
3. **Larger cross-section.** Skin-friction losses shrink relative to thrust as the duct grows.

4. **Decoupled DBD ion source.** The thesis's modeled endgame: a 10-stage MSD with a volumetric ion source could exceed **100 N/m²**. This adds an HV *AC* system (kHz, kV) on top of the DC rail — a significant electronics step up, appropriate only after the corona MSD is dialed in.
5. **Forward-speed testing.** The nozzles earn their keep only with freestream velocity — a rooftop/vehicle-independent wind source or a simple open-jet fan rig opens this chapter.