Single-Stage Ducted EAD Thruster — Build Specification

Project: EAD Propulsion, Phase 1
Reference: Gomez Vega, N. (2023). *Advances in electroaerodynamic thrusters for aircraft propulsion*. PhD thesis, MIT AeroAstro — Chapter 5 single-stage experiments (Fig. 5-1 hardware), Chapter 3 reverse-emission mitigation.
Goal: A working, instrumented single-stage corona-discharge thruster that produces measurable thrust (target: 50–300 mN) and teaches you the current–voltage–thrust behavior you'll need before attempting the multistage build.

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1. Concept

A thin wire (emitter) held at high voltage above a grounded aerodynamic surface (collector) ionizes air in the intense field near the wire (corona discharge). Ions drift across the gap, colliding with neutral air molecules and dragging them along — an "ionic wind" that produces thrust on the electrode assembly.

Enclosing the electrodes in a duct organizes the flow and lets you measure areal thrust density directly.

Why this exact geometry: The thesis found that the Coulomb force per unit volume is mostly a function of *power draw per unit area*, and that smaller gaps give better volumetric performance at lower voltage — a 15 mm gap produced up to 80% more force per unit volume than a 30 mm gap at the same areal power. Small gaps mean you can stay under 20 kV instead of the 40 kV used on the 2018 MIT airplane.

2. Design Parameters (from the thesis test article)

Parameter	Thesis value	Your build
Duct cross-section	180 × 180 mm square, Styrofoam	Same — 180 mm square, XPS foam board or foam-core
Duct height (stage)	~51 mm	50–80 mm
Emitter wire	56 μm tungsten	50–80 μm tungsten (or 0.1 mm stainless steel to start — easier to handle,

Parameter	Thesis value	Your build
		slightly higher corona onset)
Collector profile	HT14 airfoil rescaled to 10% t/c, 20 mm chord, PLA 3D print + aluminum foil skin	NACA 0010, 20 mm chord, PLA print + smooth foil wrap (NACA 0010 performed best in prior wire-to-airfoil studies and is easy to generate)
Gap spacing *d* (emitter to collector LE)	15 / 20 / 30 mm tested	**Start at 20 mm**; make holders for 15 and 30 mm too
Electrode pairs	1–13 tested	**7–9 pairs**, uniform spacing Δ = 180/N mm
Polarity	Positive corona (emitter +, collector grounded)	Same — positive corona is quieter, higher sparking voltage, less ozone

Parameter	Thesis value	Your build
Operating voltage	Up to ~18–20 kV at these gaps	15–20 kV DC
Current draw	Sub-mA per meter of emitter	Expect 0.1–0.5 mA total

3. Bill of Materials

Structure

- XPS foam board or foam-core, 5–10 mm thick — duct walls (180 mm internal square)
- PLA filament — electrode holders (two combs, one per duct wall) and collectors
- Nylon M3–M4 screws — emitter wire tensioners (thesis method: wire wraps around a nylon screw; tightening it tensions the wire)
- Epoxy adhesive, copper tape, electrical tape

Electrodes

- Tungsten wire, 50–80 μm (EDM wire spools are a cheap source) — or 0.1 mm 316 stainless for the first prototype
- Aluminum foil (heavy duty) for collector skins — must be *smooth*; wrinkles create field

concentrations

- Thin insulated hookup wire to daisy-chain collectors, routed flush against the duct exterior

High voltage

- Adjustable DC HV supply, 0–20 kV, 1–2 mA, current-limited. Options in rough order of preference: a used/surplus lab supply (Matsusada/Spellman/Glassman class — this is what the thesis used); a purpose-built adjustable HV module with metering; or, minimum viable, a flyback/CCFL-based hobby supply *with a series ballast resistor* (see §6). Built-in current metering is worth paying for — the I–V curve is half the data you want.
- HV wire rated ≥ 30 kV (silicone HV lead)
- 10 MΩ+ HV ballast resistor chain (e.g., 10 × 1 MΩ 2 W in series, potted)

Instrumentation

- Digital scale, 0.01 g resolution, ≥ 2 kg capacity — thrust balance (thesis used a 10 mg-resolution balance)
- Rigid hanging frame so the duct hangs *below* the scale (thrust pushes down through the frame; read thrust as weight change). Keep the scale ≥ 0.5 m from any HV point.

- Multimeter with HV probe (40 kV probe) for verifying output voltage — or trust the supply's meter
- Hygrometer/thermometer — log humidity every run; corona behavior shifts with it

4. Construction Sequence

Step 1 — Duct. Cut four walls for a 180 mm internal square, height 60 mm. Butt-join with epoxy. Square and rigid matters more than pretty.

Step 2 — Electrode holders. Print two comb-style holders (mirror pair). Each has: a top row of small holes for threading the emitter wire, and two lower rows of 0.9 mm holes at your gap spacing *d* below the top row, for the collector mounting pins (quarter-chord and mid-chord). Design the hole rows so one printed pair gives you your chosen Δ spacing for 7–9 electrode pairs. Epoxy the holders to opposite exterior walls.

Step 3 — Collectors. Print NACA 0010 sections, 20 mm chord, length = 180 mm minus clearance. Drill/print 0.8 mm transverse holes at quarter-chord and mid-chord. Wrap each in one smooth layer of foil. Mount by pushing steel pins through holder → duct wall → collector holes (four pins per collector). Daisy-chain all collectors electrically; this whole bus is your **ground**.

Step 4 — Emitter. Thread one continuous tungsten wire back and forth through the top hole row so you get N parallel emitter runs directly above the collector leading edges. Terminate both ends on nylon tensioning screws. If the wire sags, add an intermediate tensioning screw and bridge the cut with copper tape (thesis method). Sag ruins gap uniformity, and gap uniformity is everything.

Step 5 — Reverse-emission mitigation (Chapter 3 payoff). Reverse emission is a parasitic discharge at sharp collector ends that wastes power (up to ~64% of it in thesis tests), lowers sparking voltage, and makes noise. Mitigate from day one: (a) make collector spans slightly *longer* than the emitter span so wire ends don't face collector tips, (b) round or cap the collector ends — print small hemispherical end caps and foil them smoothly, (c) cover every external pin/wire stub with electrical tape or corona dope. A well-mitigated positive-corona thruster in the thesis was *silent* — audible hissing/crackling is diagnostic of a problem.

Step 6 — Electrical. HV(+) → ballast resistor chain → emitter bus. Collector bus → supply ground → earth ground. No sharp solder points anywhere on the HV side: ball every joint, tape every stub.

Step 7 — Thrust stand. Hang the duct (exhaust down) from the scale via a rigid non-conductive frame. Tare, energize, read Δweight. 1 g ≈ 9.8 mN.

5. Test Plan

1. **Corona onset.** Dark room, raise voltage slowly from 0. Note voltage where faint glow/current appears (expect ~8–12 kV at d = 20 mm). Uneven glow along wires = contamination or sag.
2. **I–V sweep.** Log current at 1 kV steps from onset to ~90% of spark voltage. The thesis validated a quadratic-family corona law here — your curve should be smooth; kinks mean spurious discharges.
3. **Thrust sweep.** Same steps, log Δweight. Expect single-digit N/m^2 of duct area — at 180×180 mm, roughly 30–300 mN across the sweep.
4. **Gap study.** Repeat at d = 15 and 30 mm with swapped holders. You should reproduce the thesis trend: smaller gap → more thrust per watt per volume, but lower sparking voltage.
5. **Log humidity and temperature** every run.

Data to keep: V, I, thrust, d, N pairs, RH, T. This dataset directly feeds the multistage design — the thesis built its MSD stage geometry from exactly these single-stage curves.

6. Safety — read this part twice

This is a real high-voltage project. 15–20 kV at ~1 mA is in the "very painful, can cause falls/secondary injury, and stored charge can be worse" category rather than instantly lethal territory, but treat it as lethal anyway.

- **Current-limit everything.** Supply limit ≤ 2 mA plus the 10 MΩ ballast. The ballast also stabilizes the corona and suppresses spark energy.
- **One-hand rule.** Never two hands near the rig when it could be live. Other hand in pocket.
- **Bleed before touching.** Even after switch-off, capacitance holds charge. Use a grounding stick (insulated rod + wire to earth ground) to bleed the emitter bus every time.
- **Dead-man switching.** Power the HV supply through a switched outlet you can kill without reaching toward the rig.
- **Ozone.** Corona makes ozone and NOx. Ventilate; don't run for long periods in a closed room. If you can strongly smell it, ventilation is inadequate.
- **Dry conditions.** New Mexico's low humidity is actually favorable — but log RH anyway; thesis data spanned ~29–73% RH.
- **Perimeter.** No spectators, pets, or flammables within 2 m of an energized rig. HV leads never draped over conductive surfaces.

- **Spark ≠ failure, but stop.** If it sparks, power down, inspect for carbon tracks on foam/PLA, and clean or replace tracked parts. Carbon tracks are conductive and will spark again at the same spot.

7. Success Criteria & Exit to Phase 2

You're ready for the MSD build when you have: (1) stable, silent operation at ≥ 15 kV for 10+ minutes; (2) repeatable I–V and thrust–V curves at two gap spacings; (3) measured thrust density ≥ 3 N/m^2 (single-stage ceiling per the literature is ~3–30 N/m^2 depending on definition and geometry — anything in single digits means your rig is healthy).