WEEK 3

Article: Shen *et.al.*, Sunlight-powered sustained flight of an ultralight micro aerial vehicle, *Nature*, 2024.

QUESTIONS 3a

1. The rotor blades of the ES-Drive seem to act as an impeller moving air from outside of the cylinder to the inside. That seems to be wasted power. Would there be a way to use that power?

2. The electrostatic motor used in the CoulombFly employs electric brushes to transfer charge between stator and rotor plates, whereas corona motors maintain an air gap between the rotor and stator, relying on air ionization to facilitate charge transfer. The use of electric brushes instead of the Corona effect is claimed to improve substantially the performance of the electrostatic motor, by reducing the voltage losses while inducing friction losses. The stator uses brushes to change the polarity of the rotor blade. I would expect high friction losses from these brushes. Since corona motors rely on air ionization, they typically require operating voltages above the air breakdown threshold. However, the referenced corona motor operates around 1–2 kV (reference number 29), while the CoulombFly operates at 4–9 kV. How would you explain this apparent discrepancy in operating voltages between the two motor types?

3. In the sunlight-powered flight tests, the MAV was guided vertically using two rails to "maintain its lateral position". Could you explain the primary reasons for using these rails? Specifically, was the use of vertical rails necessary due to inherent stability challenges, aerodynamic factors, or limitations of the propulsion/control system? What would happen if these rails are removed? Will the robot turn on itself? Unlike rotary-propelled drones, the CoulombFly MAV has no active stabilization system and depends on guide rails for vertical lift tests. Could electrostatic thrust vectoring (by varying electrode voltages) provide a way to control yaw, pitch, and roll without adding weight?

4. In Figure 2f, while the lift force increases with applied voltage and lift-to-power efficiency decreases. Since electrostatic propulsion relies on field-induced forces rather than mechanical torque generation like electromagnetic motors, what underlying factors contribute to this saturation in efficiency at higher voltages? Could phenomena such as corona discharge or air ionization be responsible for the diminishing returns, and what strategies could be implemented to mitigate these effects and extend the propulsion system's optimal operating range?

5. Unlike electromagnetic motors, the electrostatic motor in CoulombFly produces an almost constant torque. How does this affect the vehicle's stability and maneuverability compared to traditional propulsion systems? How does the electrostatic motor exhibit a nearly constant torque across varying loads, and what underlying physical or electrical mechanisms contribute to this self-regulating behavior? As we can see on video 2 the blades change their electrical sign when they pass an electric brush. Is the torque constant between two consecutives electric brushes?

6. The assumption that "higher switching frequencies improve performance" is deeply rooted in classical power electronics theory and industry practices enabling smaller components ($L \sim 1/f$ and $C \sim 1/f$) and faster response. This rationale drives modern electronics—from smartphones to laptops—to adopt MHz-range switching frequencies, shrinking power supplies and reducing weight. Yet this study's ultralight kilovolt converter defies convention, performing optimally at 86 kHz—not MHz—exposing flaws in universal high-frequency assumptions. Why does this system invert the rule, and what does it mean for extreme miniaturization? What physical or circuit-level phenomenon causes the output voltage to dip at fh, and how does this frequency relate to the resonant properties of the Cockcroft-Walton multiplier or parasitic components in the forward-flyback topology?