Conceptual Aircraft Design – Elec. Powertrain Sizing

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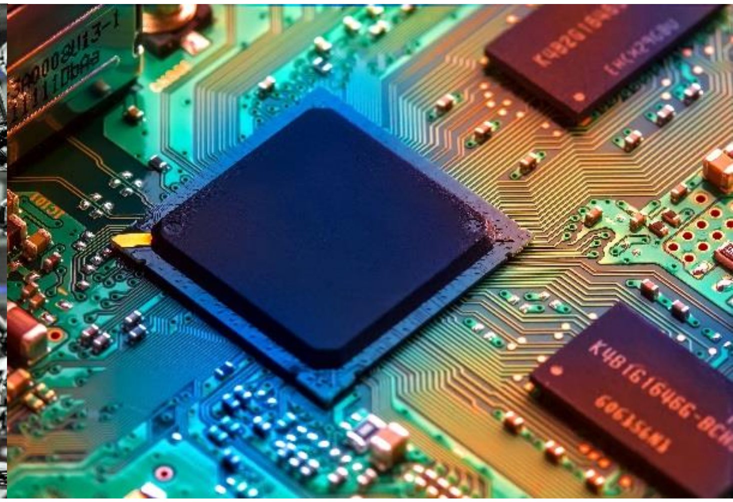

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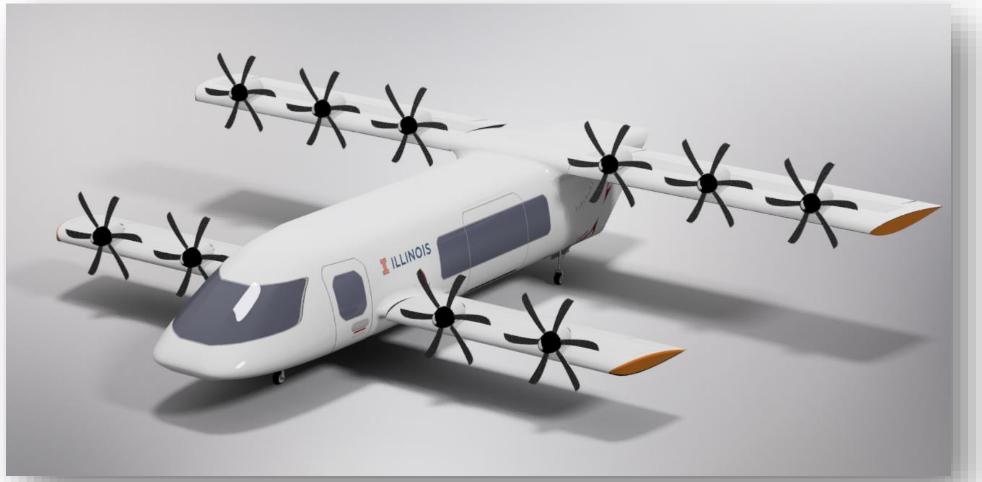
Why Electric Aircraft?



Environmental Impact

- Aircraft emissions disproportionately impact air quality
- High-altitude emissions have greater climate impact

Reliability

- Electric machines have 1 moving part
- Many motors, low impact of single failure

Propulsion Integration

- Small electric motors can integrate closely with wing/fuselage and improve overall vehicle aerodynamics

Cost

- Similar to electric cars, operating costs may go down
- Independence from oil volatility

Traditional Aircraft Conceptual Design

Aircraft design is a well-established process that leverages empirical methods…

Requirements Generation
Metrics defining a successful design are quantified

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Weight Estimation
Initial guess at vehicle empty weight (usually empirical)

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Constraint Curves
Thrust and wing loading plots which bound the viable design are generated

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Configuration Design
Overall vehicle layout is created, informed by mission requirements and prior designs. Lifting and control surfaces are designed with structural elements. Minor subsystem weights are estimated, and internal packaging is considered.

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Refined Weight Estimation
Knowledge of vehicle geometry and rough structural layout permit refinement of mass budget. Center of Gravity is estimated.

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Performance Analysis
Empirical and low-fidelity physics methods used to predict flight characteristics

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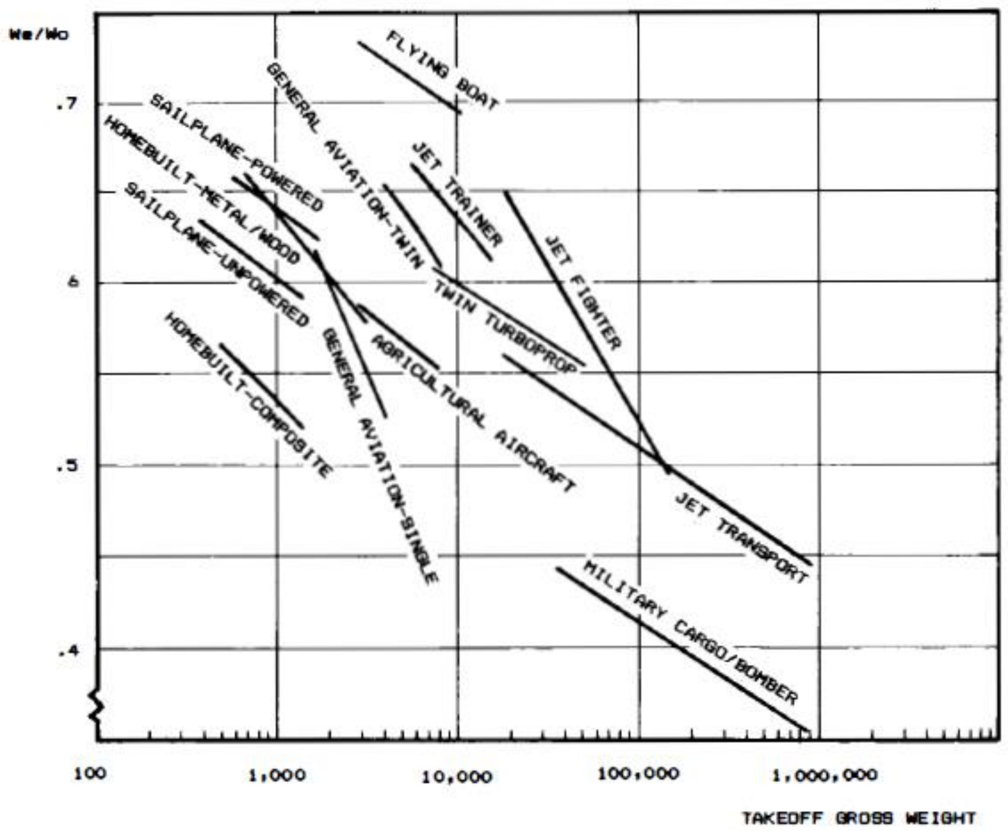
Verification
Detailed analysis or physical experiments check that design meets requirements



(Reproduced from Aircraft Design: A Conceptual Approach by Raymer)

… but physics-based models are gaining traction.

Adapting Design for Electric Aircraft

Reliance on empirical data means existing processes are *not* well-suited to electric aircraft. We need a way to roughly determine the size and mass of an electric powertrain without detailed analysis:

Electric Machines

Torque/Speed requirements can be determined from propeller model. Then machine can be sized using shear stress theory:

$$T = \frac{\pi D_{ag}^2 L}{4} A_{peak} B_{peak}$$

Electrical & Magnetic Loading can be assumed reasonably constant for well-designed MW-class electric machines

Energy Storage

Energy Storage must be sized for energy & power (conventional aircraft decouple these). Need to find best split between high energy (battery/fuel cells) and high power (supercapacitors):

$$SP_{avg} = H_{HED} SP_{HED} + H_{HPD} SP_{HPD}$$

$$SE_{avg} = H_{HED} SE_{HED} + H_{HPD} SE_{HPD}$$

Power Electronics

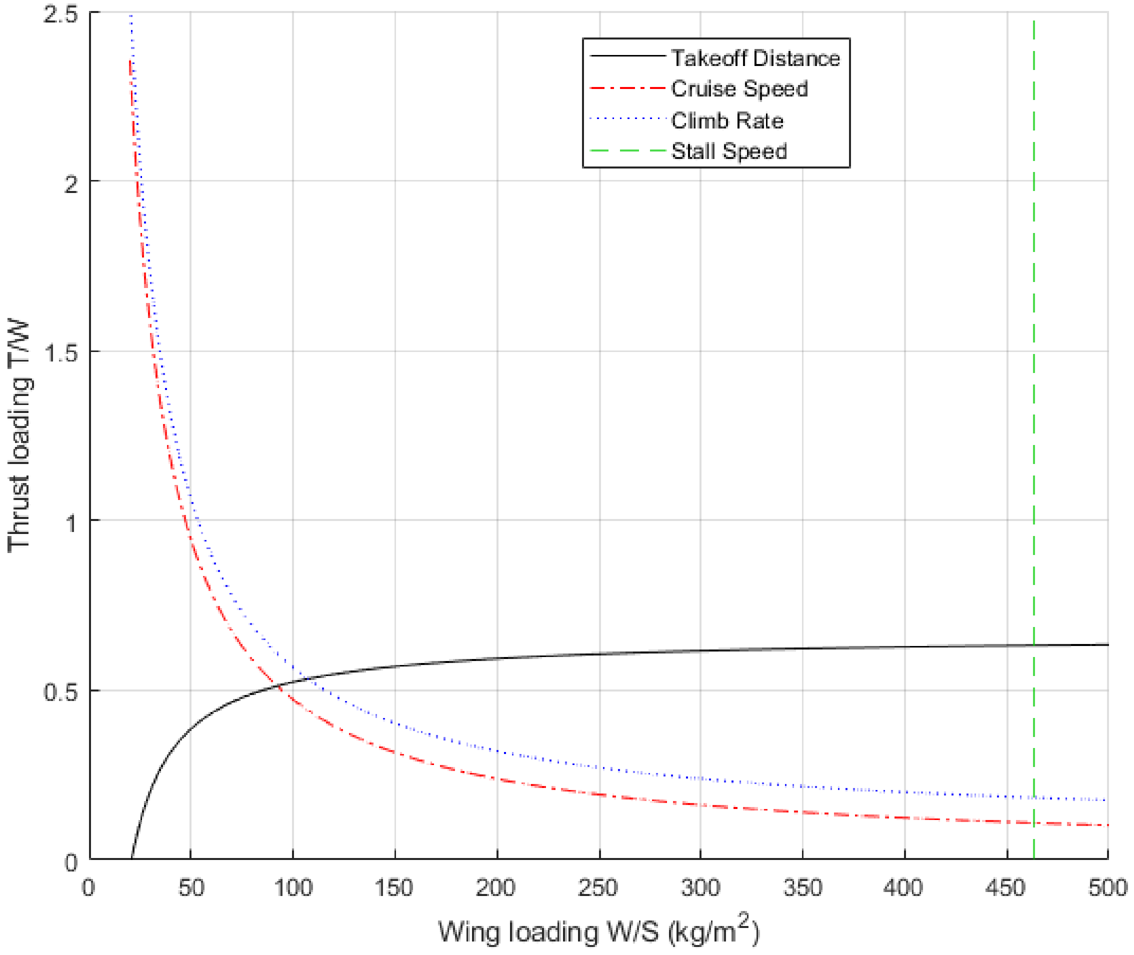
The most important component is the inverter: DC energy storage, AC machines. Contemporary inverters achieve:

SP: 19 kW/kg

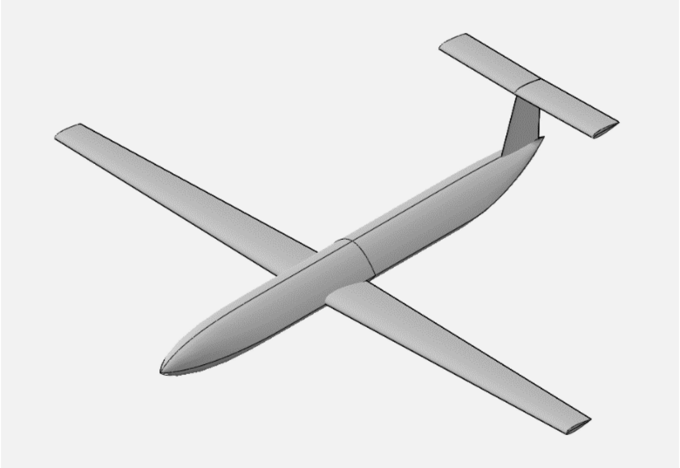
PD: 14 kW/L

Transmission hardware assumed 5% of the total, based on other detailed design studies

Example Design Study – MALE Sensorcraft



$$m = m_{ref} \frac{E_{req}}{E_{ref}} \frac{U_{fuel}}{U_{battery}}$$

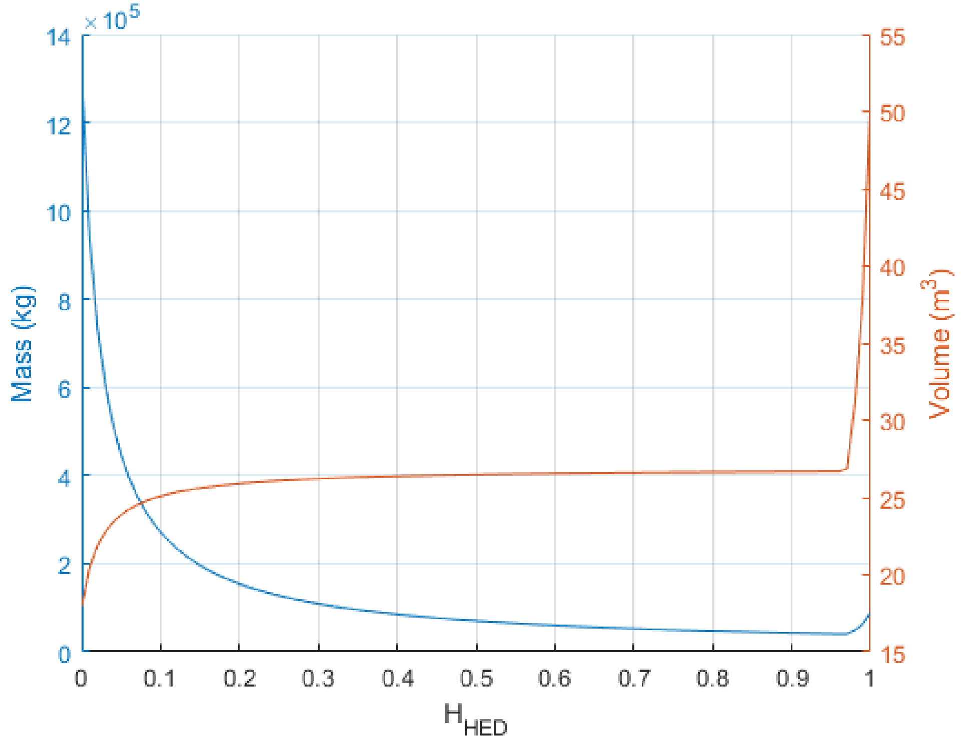


Initial Mass Estimate	49,200
Non-Propulsive Mass	10,362
Mass Budget	38,838

No credit for near-term technology improvements

Example Design Study – Results

Battery/supercap split:



Component	Mass (kg)	Volume (m^3)
Motors	3245	8.608
Inverters	1708	2.318
Energy Storage (HED)	31515	15.76
Energy Storage (HPD)	1313	0.0073
PMAD	1068	N/A
Propellers	1797	N/A
Total	40,646	26.69

4.65% error between propulsion mass estimate and budget

Conclusions

- This process illustrates the **vehicle-level** impact of the capabilities of the component technologies. Compare:

  Embraer E190 – 51800 kg, 450 kn, 6 hr endurance

  New Design – 49200 kg, 200 kn, 1 hr endurance

- Incorporating new technologies in aircraft design requires understanding of how the tech interfaces with all vehicle systems
- Empirical methods are still useful, but trend towards physics-based models in useful for revolutionary aircraft
- Experimental work to improve electric machines ongoing…

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