A general approach to conceptual design of hybrid-electric aircraft

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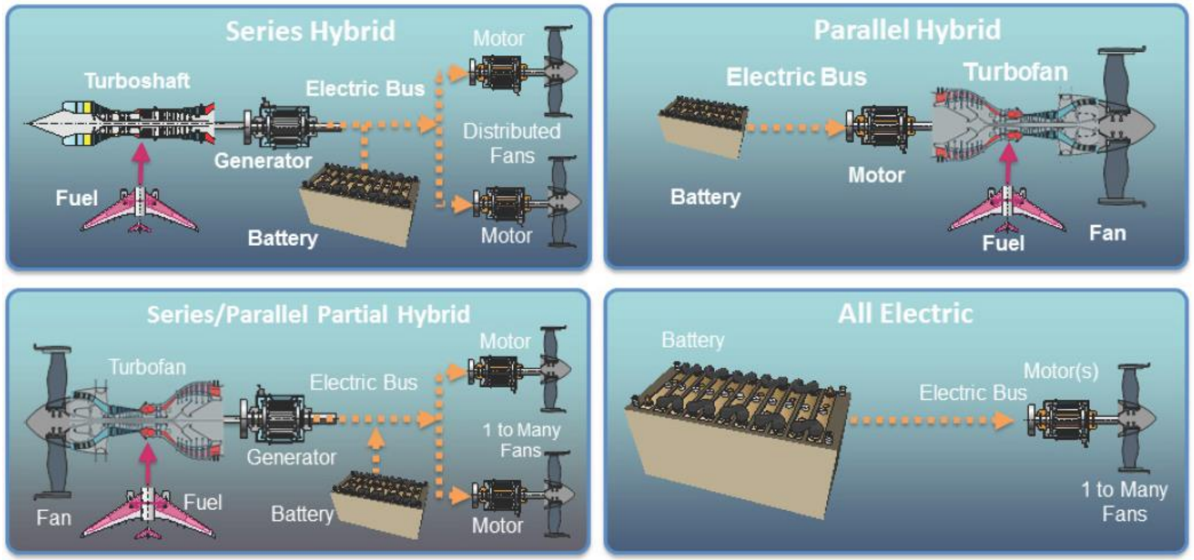
Outline

1) Introduction
   - Hybrid architectures
   - Future trends
2) Sizing Approach
   - Preliminary aircraft sizing
   - Working assumptions
   - Motors and Battery sizing
3) Numerical Implementation
   - *Hyperion* program procedure
   - Simulation strategies
   - Program validation
4) Results
   - General aviation case study
   - Micro feeder case study
5) Conclusions

Introduction: hybrid architectures

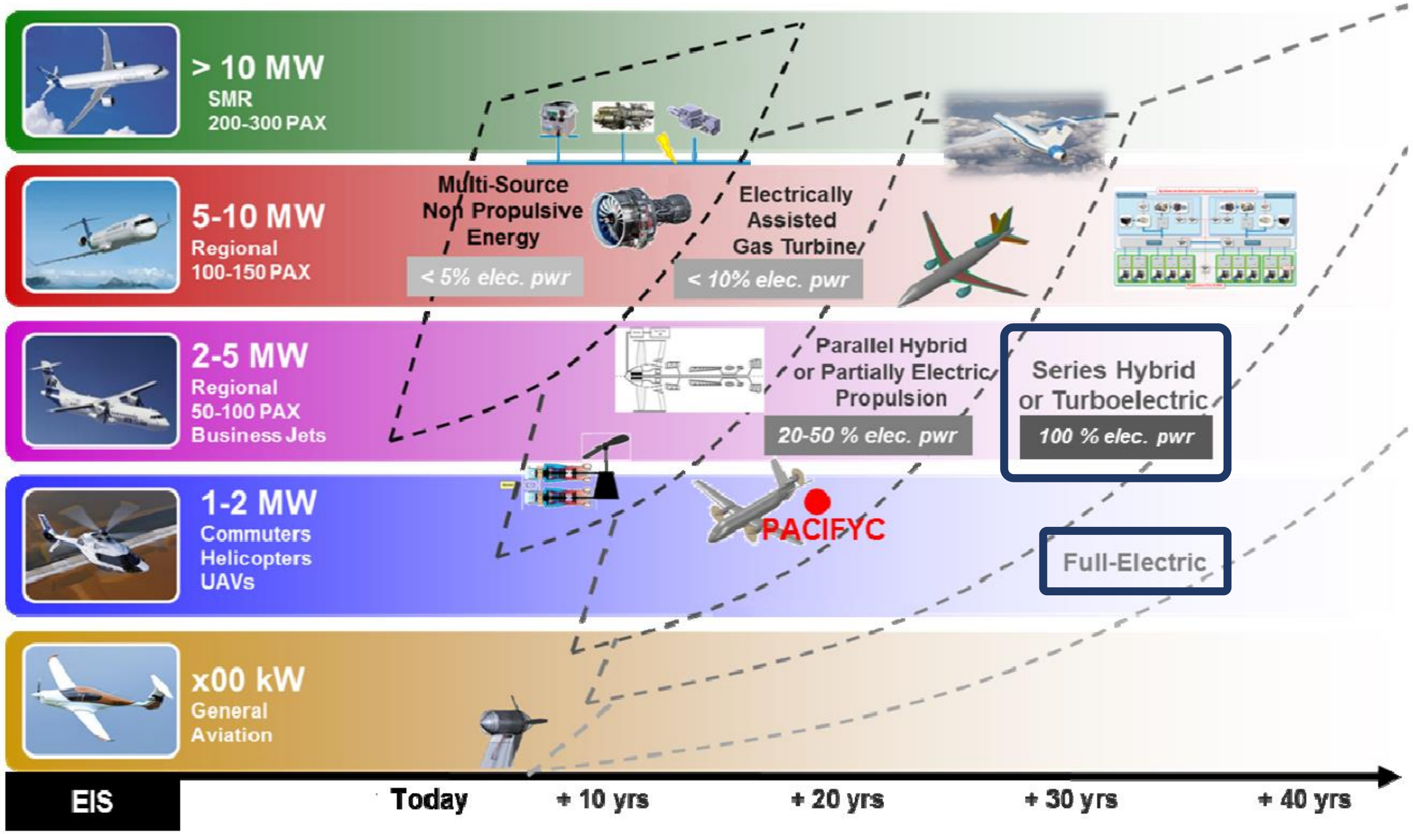


Available architectures

- All Electric
- Series Hybrid
- Parallel Hybrid
- Series/parallel Hybrid

Source: *Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions, National Academies Press.*

Introduction: future trends



Source: *Long-term Hybrid-Electric propulsion architecture options for transport aircraft, A.T. Isikveren, Y. Fefermann, C. Maury , 2016.*

Trend of applications

- Non propulsive energy
- Electrically assisted gas turbines
- Parallel hybrid propulsion
- Series hybrid or Turboelectric
- Full-Electric

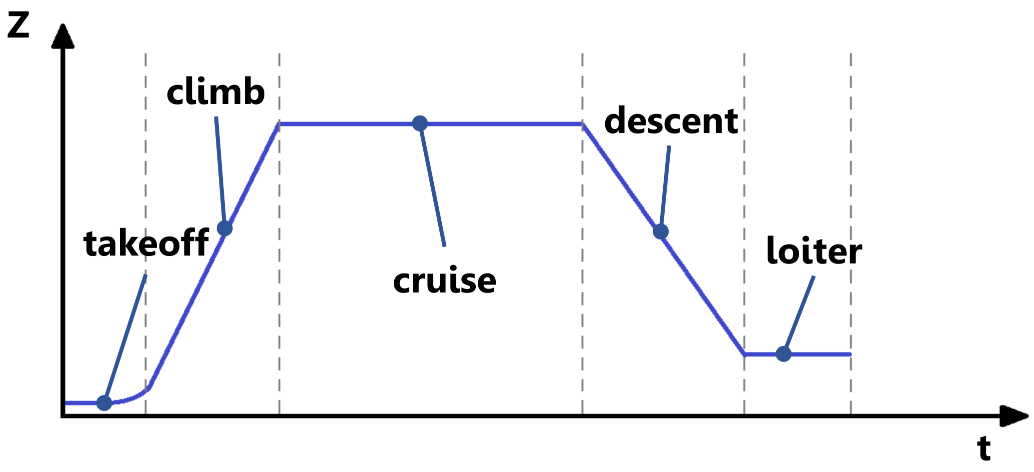
Outline

Sizing Approach: aircraft preliminary sizing

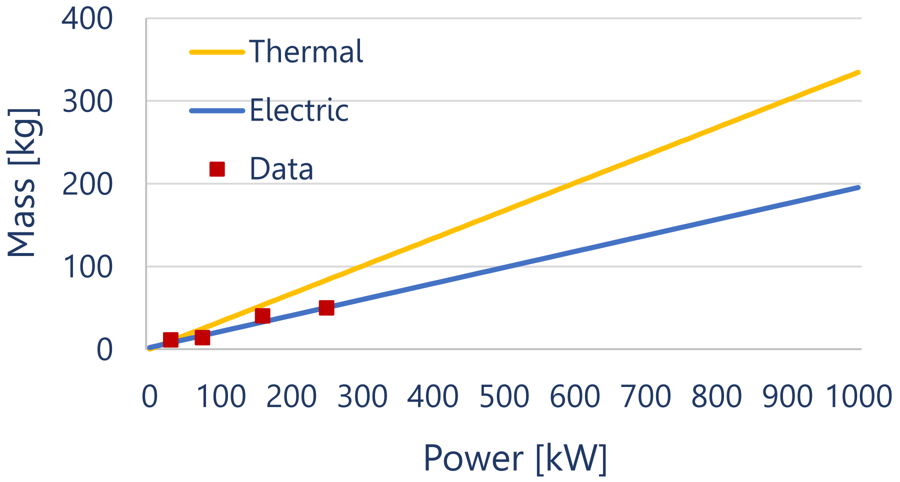
Airplane conceptual design

- Computation of aircraft takeoff, empty and payload mass
- Estimation of aircraft aerodynamic characteristics and performance
- Determination of required power and mission energy
- Computation of motor and generator power and fuel and battery mass

Flight profile definition



Engines Regression



Sizing Approach: working assumptions

Source: *hypstair.eu*

Power-train

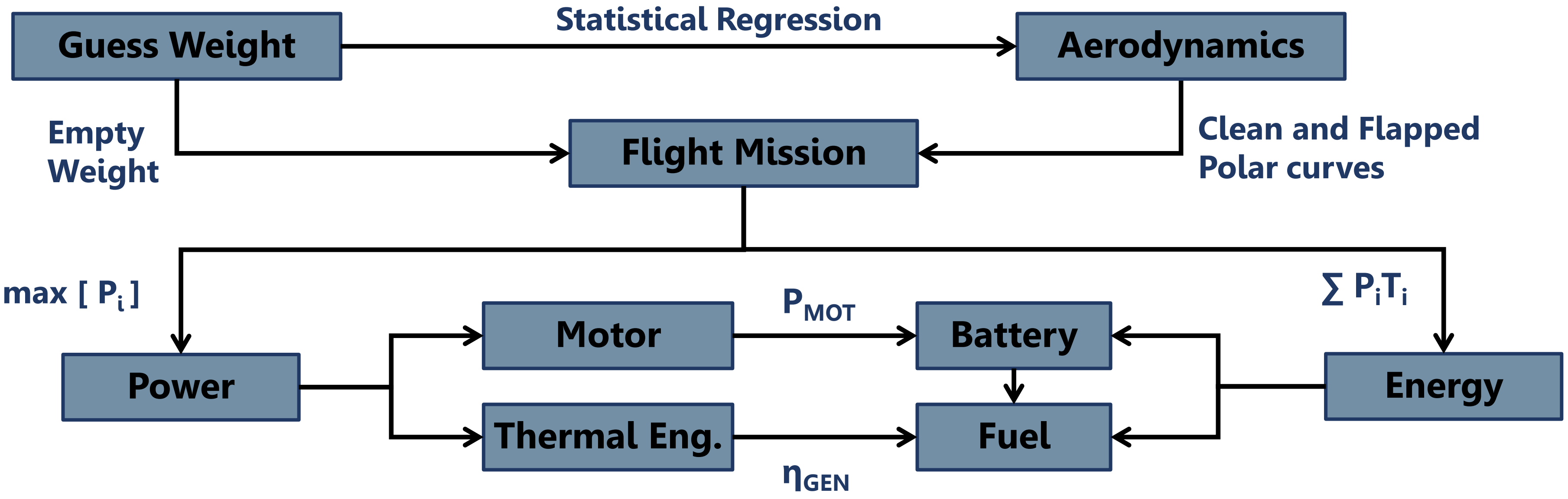
- Use of propellers driven by electric motors
- Power provided by batteries
- Motor power not depending on altitude
- Windmilling allowed in descent phase
- Generator: turboshaft or reciprocating engine with alternator

Generator model

- Simulation of the thermodynamic cycle at every altitude with estimation of real efficiency through experimental parameters
- Fuel flow rate obtained from needed power from flight mechanics
- Selection of a transition altitude for generator operation

Sizing Approach: motors and battery sizing

- Aircraft empty mass and aerodynamic characteristics from statistical regression
- Analysis of needed power, estimated duration and overall energy for each phase
- Motor and Generator sizing based on maximum and cruise power respectively
- Battery and fuel mass from required energy and power needs



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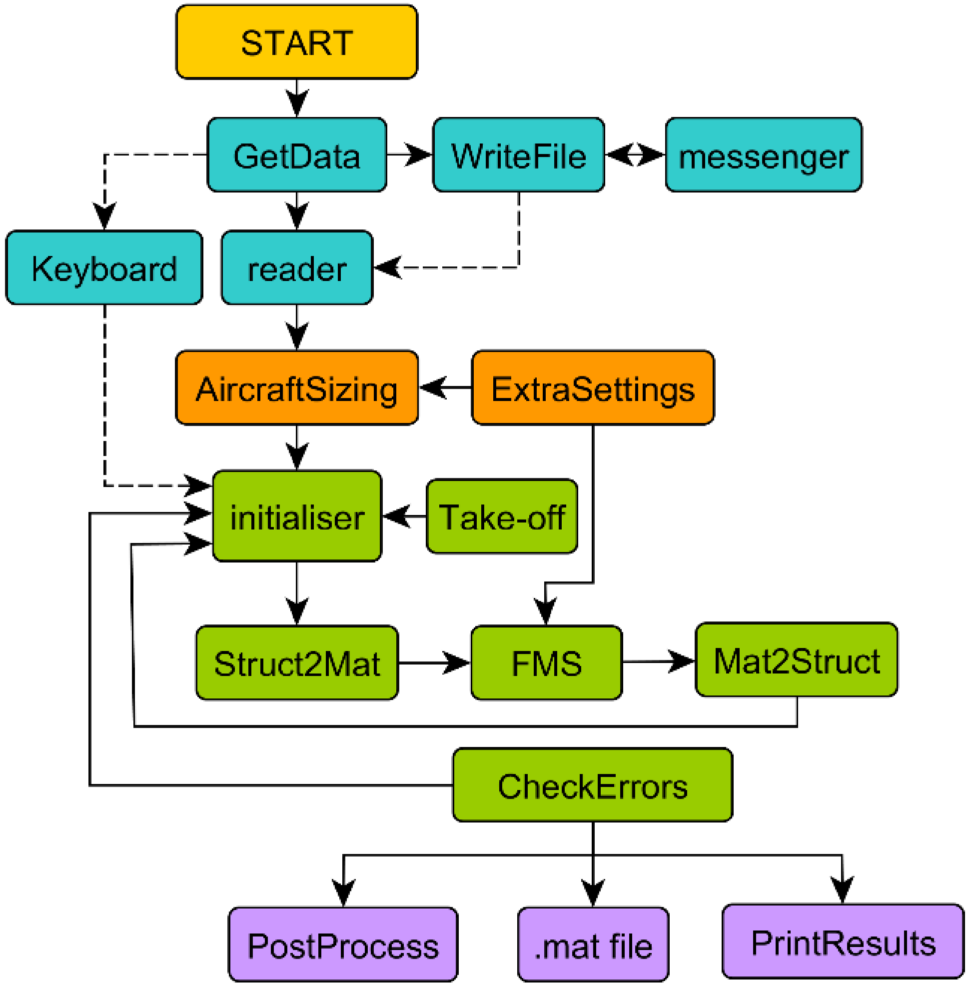
Numerical Implementation: *Hyperion* program



Hyperion: HYbrid PERformance simulatION

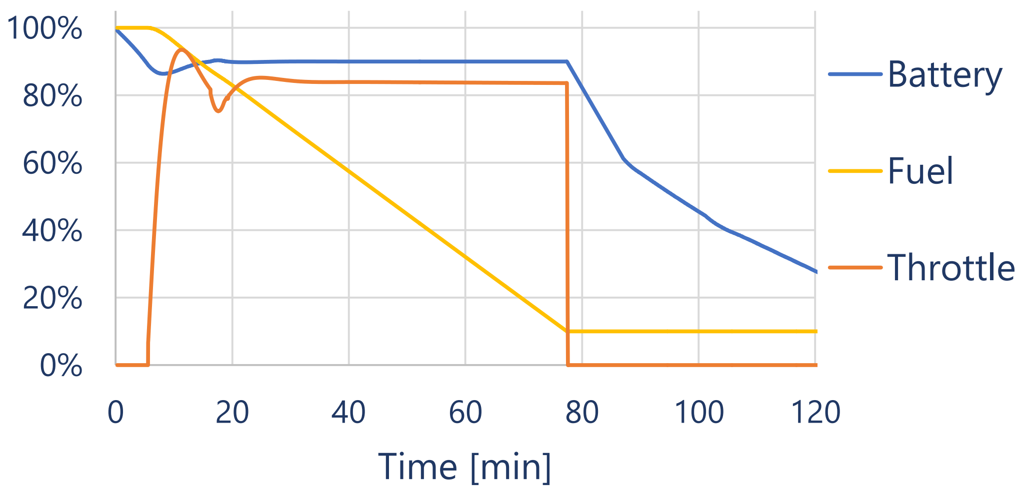
- Program initialization through input file
- Simulation settings selected by user
- Preliminary aircraft sizing
- Step-by-step simulation of each flight phase
- Check on final fuel and SoC levels
- Battery/Fuel mass correction and re-iteration until convergence
- Visual postprocess and file writing

Numerical Implementation: simulation strategies

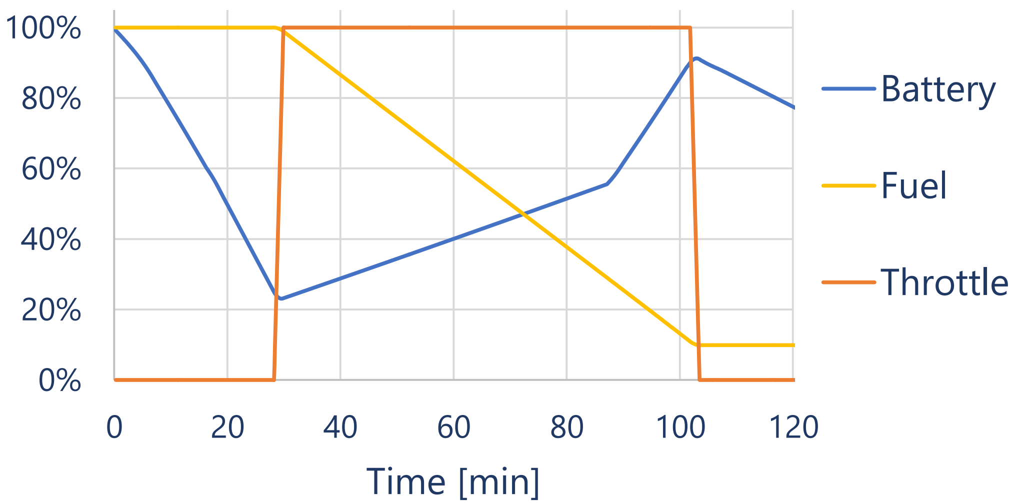
Battery charging Strategy

- Based on battery state of charge, returns generator throttle for subsequent time step
- Evolution through PID controller: more realistic throttle characteristics
- Generator turned off during takeoff and first climb segment
- Divided in **steady charging** and **cyclic charging** strategies

Steady charging strategy

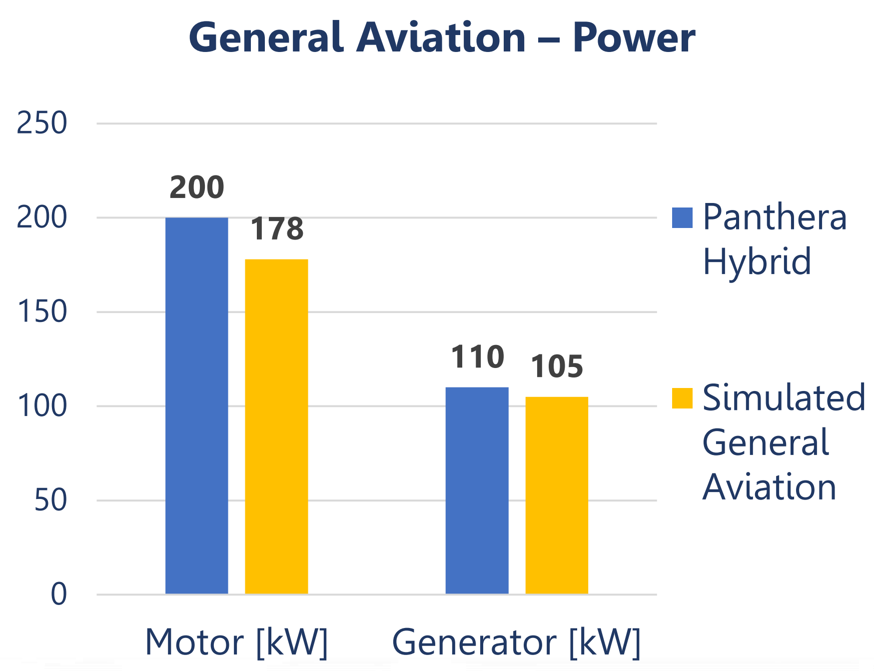


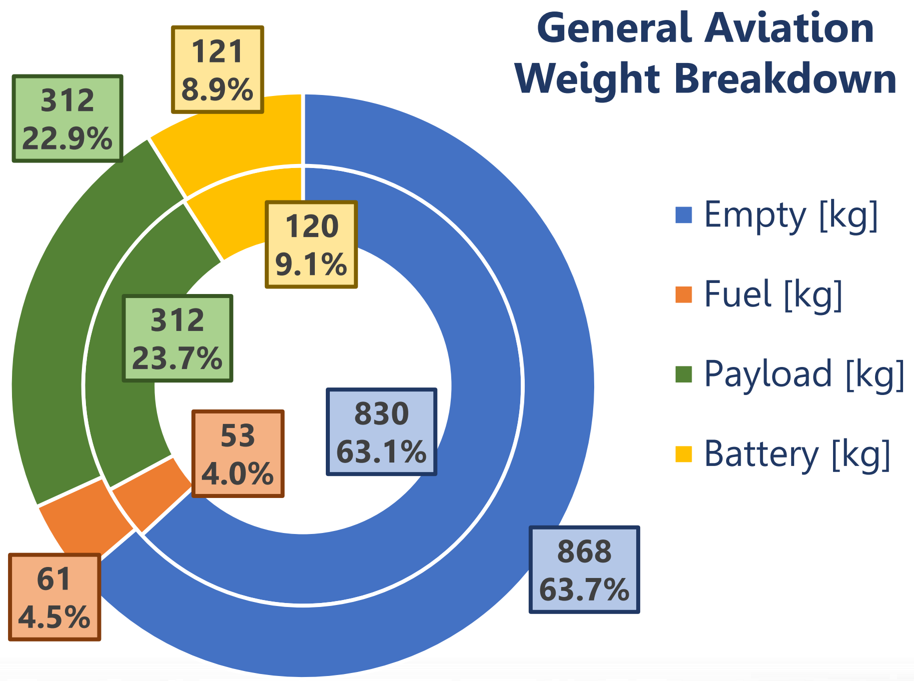
Cyclic charging strategy



Numerical Implementation: program validation

- Validation on general aviation, micro feeder, commuter and regional aircraft classes
- Validation based on aircraft weight breakdown and installed power
- Conventional airplanes simulated as turboelectric
- Validation on Panthera Hybrid (internal ring)





Numerical Implementation: program validation

Aircraft		M_{TO} [kg]	M_E [kg]	M_F [kg]	S_W [m^2]	P_M [kW]
Micro feeder Tecnam P2012	Real	3600	2250	275	25.4	560
	Simulated	3327	1927	304	24.0	443
Commuter Beechcraft Beech-1900D	Real	7764	4732	894	28.8	1910
	Simulated	7659	4707	814	28.2	1860
Large regional ATR 72-600	Real	23000	13500	2000	61.0	3650
	Simulated	22990	13450	1920	61.8	3930

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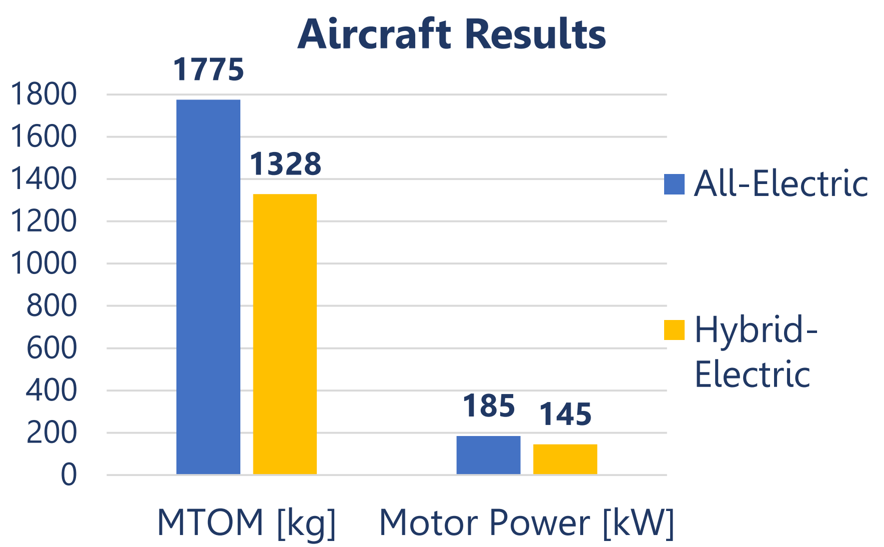
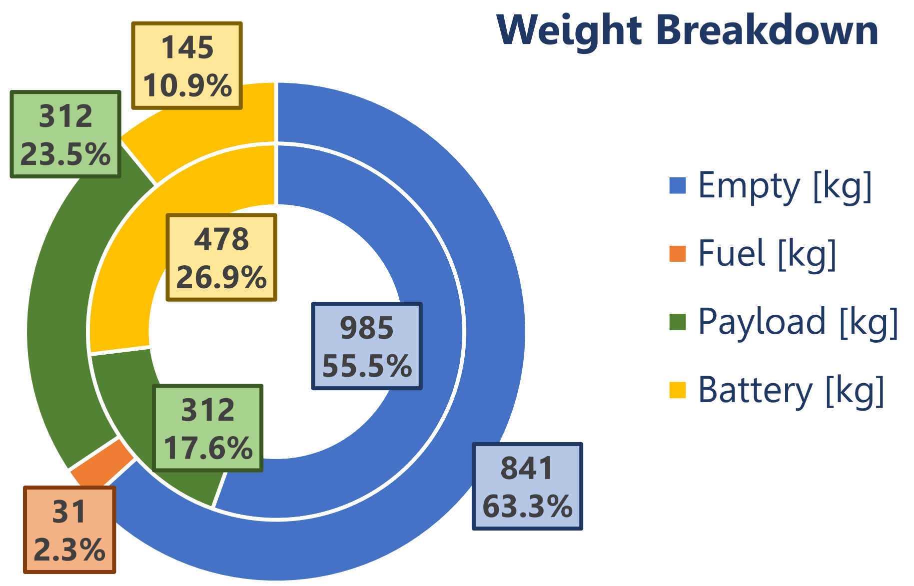
Results: general aviation case study

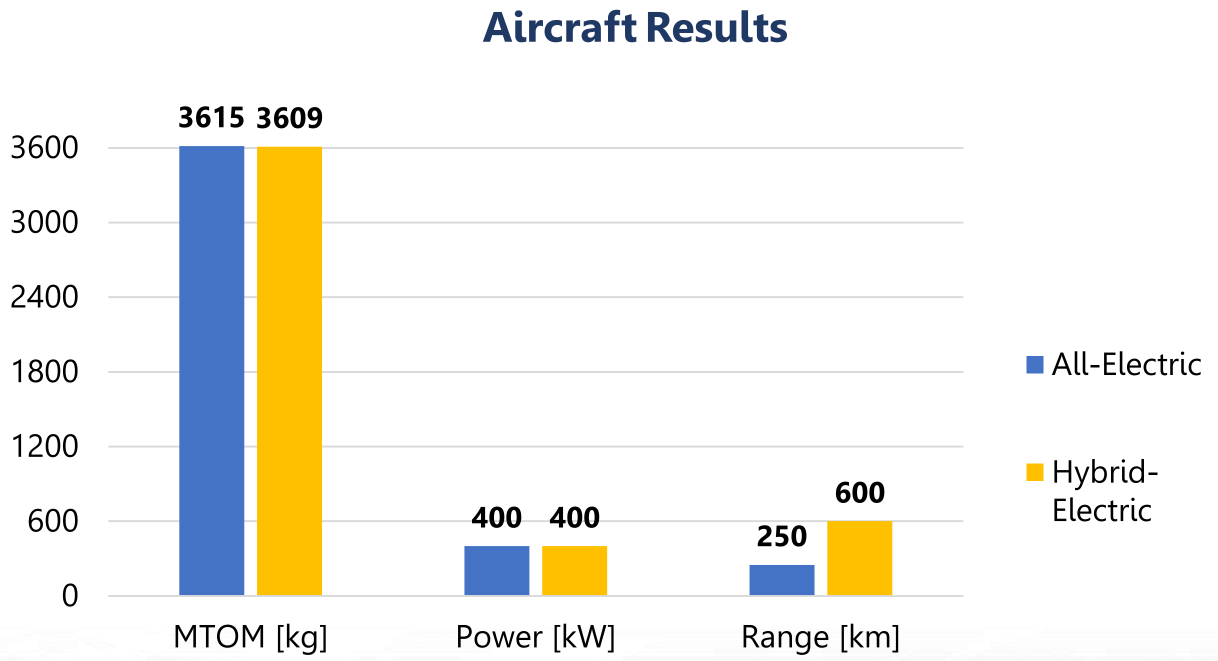
- Study on a single-engine, 4-seater general aviation aircraft with range of 300 km
- Comparison of an All-Electric (internal ring) and Hybrid-Electric (external ring)
- Battery with 1000 W kg^{-1} and 500 Wh kg^{-1} of specific power and energy
- Final state of charge (SoC) of 25% and 10% fuel reserve

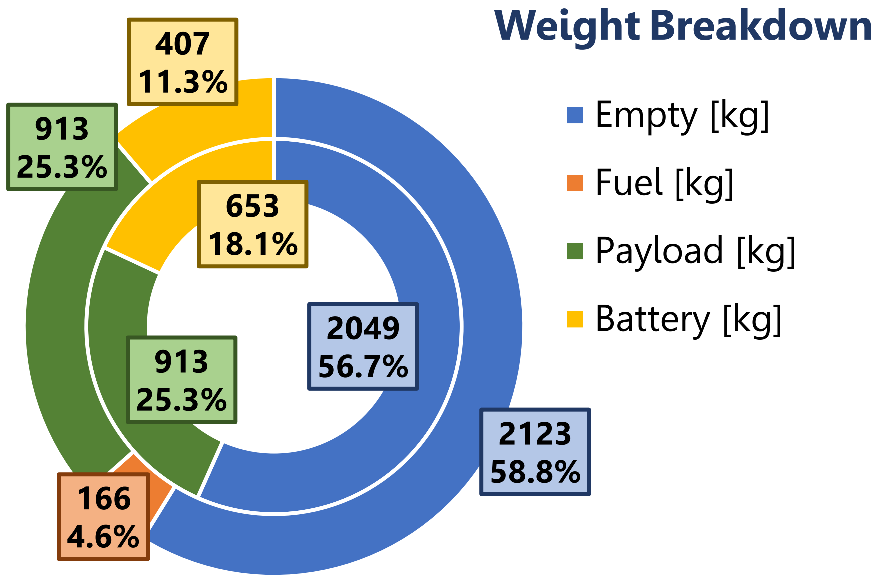




Results: micro feeder case study

- Study on a twin-engine, 8-seater micro feeder aircraft with range of 250 km All-Electric and 600 km Hybrid-Electric
- Comparison of an All-Electric (internal ring) and Hybrid-Electric (external ring)
- Battery with 1000 W kg^{-1} and 500 Wh kg^{-1} of specific power and energy
- Final state of charge (SoC) of 25% and 10% fuel reserve





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Conclusion

- Developed a general procedure for All-Electric and serial Hybrid-Electric aircraft conceptual design using turboshaft or reciprocating generator
- Conducted validation on available hybrid aircraft and simulated conventional limit case
- Conceptual design of All-Electric and Hybrid-Electric 4-seater general aviation aircraft and 8-seater micro feeder aircraft

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- **Develop hybrid electric serial powertrains** to enable cleaner, **quieter** and **more efficient** aircraft propulsion
- Deliver **optimized propulsion components** with increased reliability suitable for **commercial deployment** to small aircraft

mahepa
Modular Approach
to Hybrid Electric
Propulsion Architecture

PIPISTREL

Thank you for your attention!