Cost Estimation Methods for Hybrid-Electric General Aviation Aircraft

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Motivation


Airbus E-Fan X


Diamond DA40 Hybrid


Pipistrel Panthera Hybrid


NASA Pegasus


Rolls-Royce eVTOL


ZUNUM Aero


Daher/ Safran/ Airbus EcoPulse

[Graphics: OEMs]

Motivation

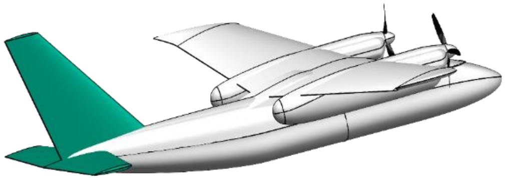
Can the traditional cost estimation methods be applied to hybrid-electric aircraft?

Do we need to consider unconventional design points, when optimizing aircraft with hybrid-electric propulsion systems?

[Graphics: OEMs]

Agenda

- Motivation
- Approach
  - Cost Estimation Methods
  - Modification of CER for Hybrid-Electric Aircraft
- Example
  - STOL Air Taxi
- Summary



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Approach

Total program cost includes

- Engineering labor costs
- Tooling labor costs
- Manufacturing labor costs
- Manufacturing materials costs
- Development support costs
- Fight test costs
- Quality control costs

Total service provision costs includes

- Variable Direct Operating Costs
  (energy, crew, landing fees, maintenance)
- Fixed Direct Operating Costs
  (depreciation, insurance, inspections, storage)
- Indirect Operating Cost
  capital expenditures, selling, general,
  administration expenses.

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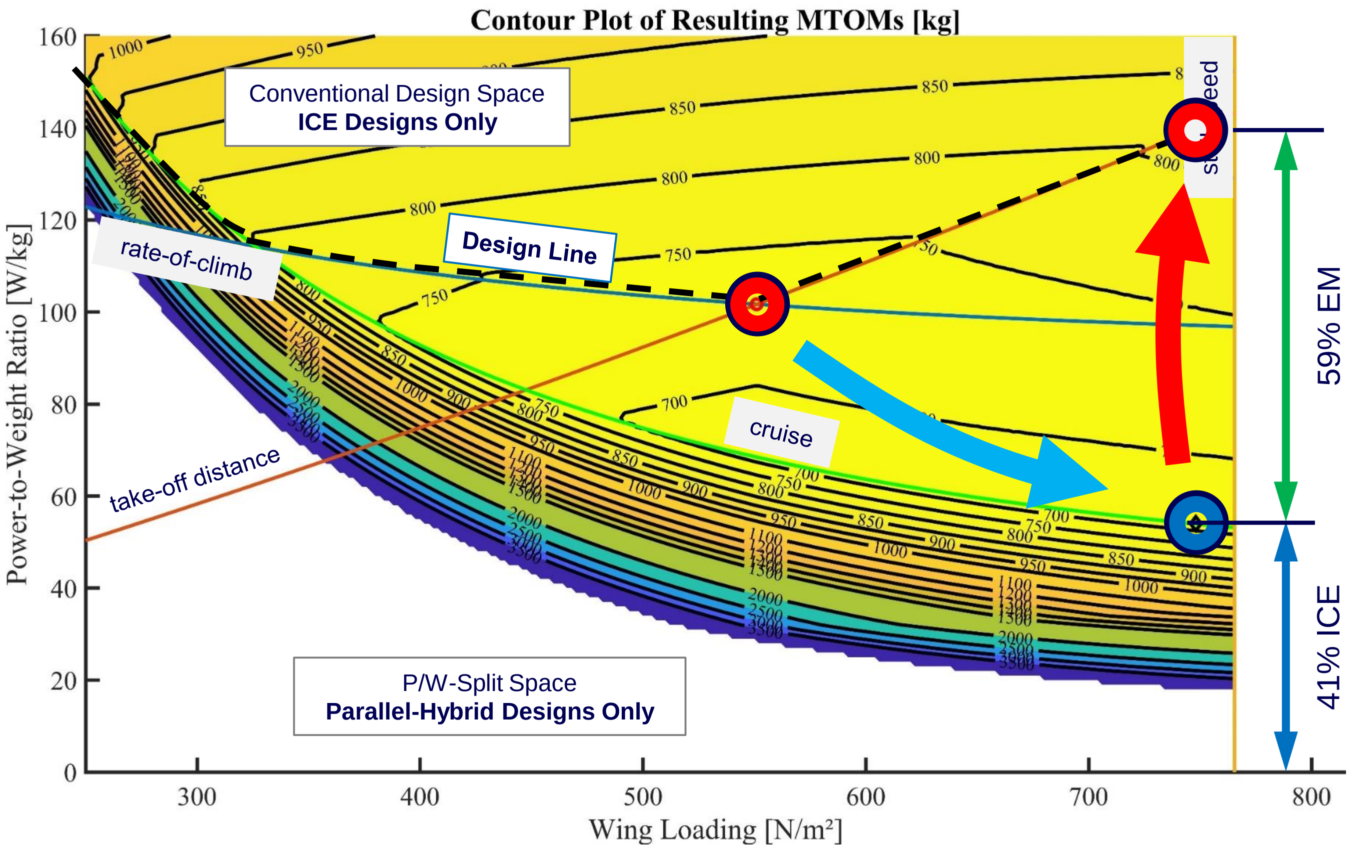
Approach

CER Category	F_{Cert} Factor for LSA certification	F_{Comp} Factor for 100% composites	F_{Taper} Factor for untapered wings	F_{CF} Factor for complex flap system	F_{Press} Factor for pressurized cabin	F_{HyE} Factor for hybrid-electrics
Engineering Cost	0.67	2.00	-	1.03	1.03	1.33-1.66
Tooling Cost	-	2.00	0.95	1.02	1.01	1.10
Manufacturing Cost	0.75	1.25	-	1.01	-	1.10
Development Support Cost	0.50	1.50	-	1.01	1.03	1.05
Flight Test Operations Cost	0.50	-	-	-	-	1.50
Quality Control Cost	0.50	1.50	-	-	-	1.50
Materials Cost	0.75	-	-	1.02	1.01	1.05

Design Methodology



Example: STOL ODAM Concept

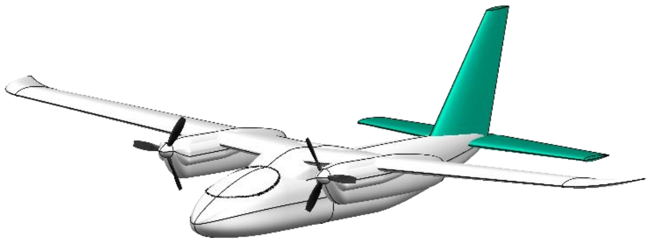
Requirements

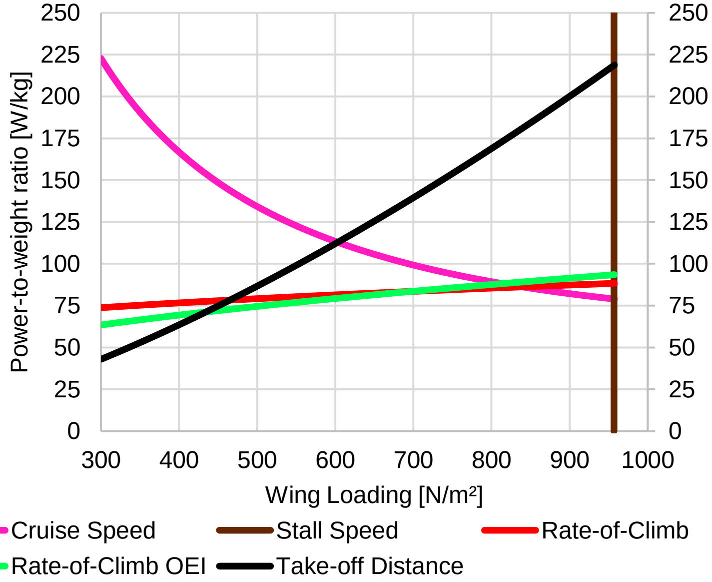
- STOL aircraft
- Intra-urban transport

- 8 seats (incl. Pilot)

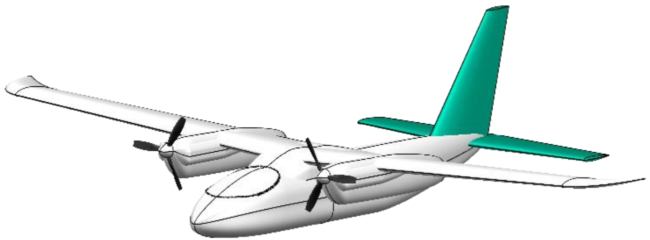
- Take-off ground roll: 150 m
- Stall speed 25 m/s

- **Parallel-hybrid** propulsion system
- Power shaving operation strategy





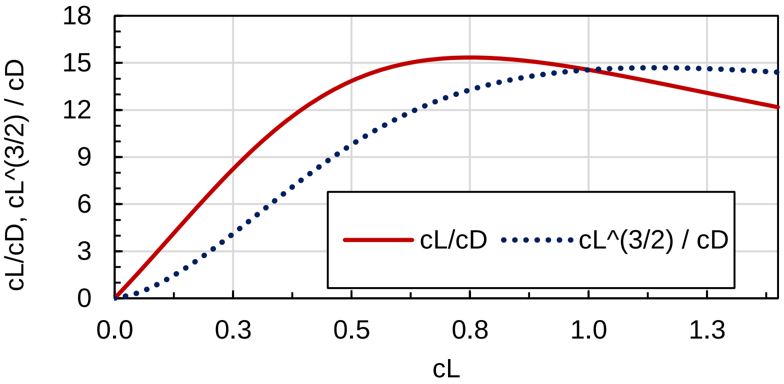
Example: STOL ODAM Concept

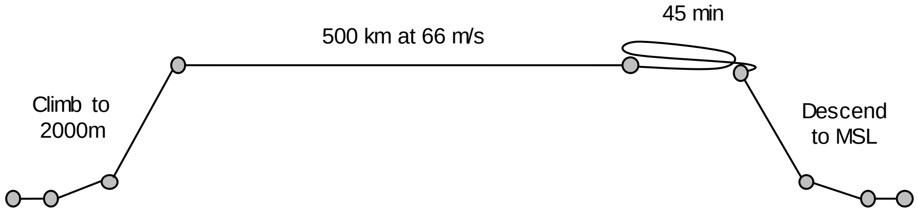


Requirements

Only variation: battery specific energy

Technology Assumptions	Technology Level		
Combustion Engine Technology	4-stroke ICE		
ICE Specific Power [kW/kg]	1.00		
ICE BSFC [g/kW/h]	315		
EM Specific Power [kW/kg]	5.00		
Battery Specific Energy [Wh/kg]	**250**	**500**	1000
Battery Discharge C-rate	20C		
Flap System	Fowler Flaps		
$C_{L,max}$	2.50		





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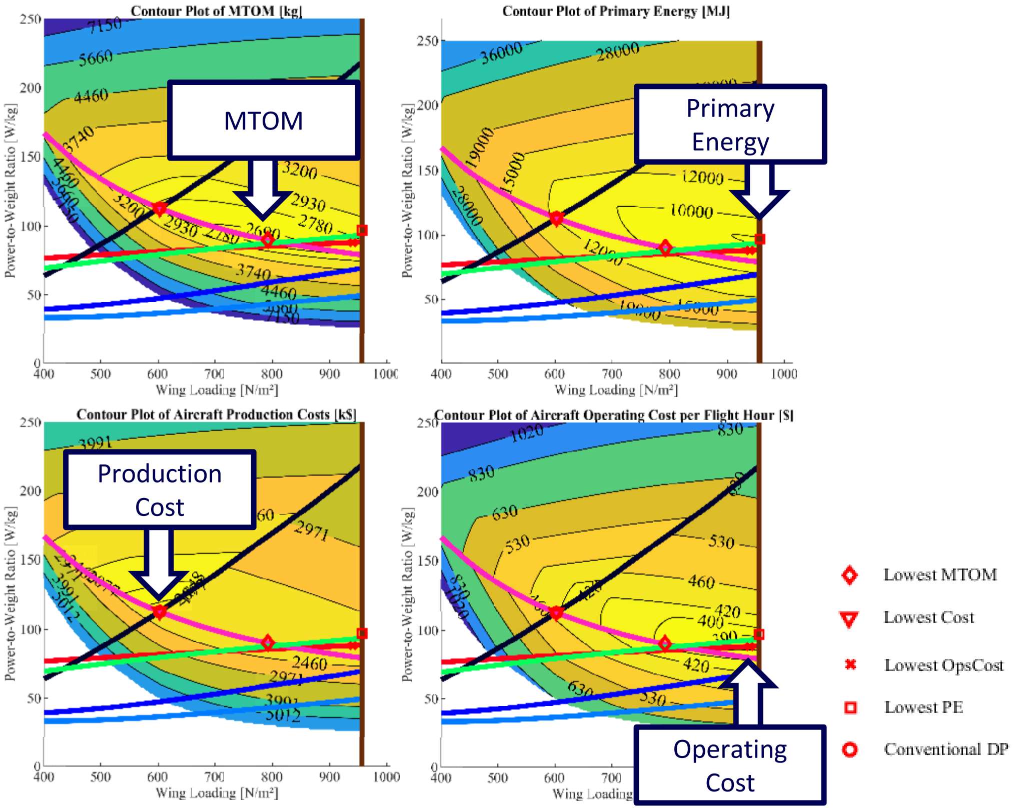
Example: STOL ODAM Concept

500 Wh/kg Batteries

Design Point	Conv. Design	MTOM	Primary Energy	Production Cost	Ops Cost
MTOM [kg]	2736	2736	2982	2736	2822
PE [MJ]	11639	11639	9777	11639	10335
Production Cost [k$]	1695	1695	2423	1695	1789
Ops Cost [$/h]	424	424	416	424	405
Hybridization	-	46%	43%	-	59%
ΔMTOM	baseline	-3%	3%	0%	1%
ΔPrimary Energy		-16%	-23%	0%	-22%
Δcost		25%	37%	0%	32%
Δops Cost		-6%	-8%	0%	-9%



Summary

- New approach for cost estimation of hybrid-electric general aviation aircraft
- Hybrid-electric aircraft are more expensive to produce,
  but cheaper to operate, compared to conventional designs
- Design point for min. operating cost and min. primary energy consumption are found very close together
  - Saving energy and reducing cost are not exclusive objectives

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