Hamburg Aerospace Lecture Series



https://heartaerospace.com/es-30

The Future of Electric Aircraft

Will there be an Electric Future in Commercial Flight?

https://doi.org/10.5281/zenodo.15659765

Dr. Thomas SCHERER, Energie-Systeme, Hamburg

12.06.2025, Hamburg University of Applied Sciences (HAW Hamburg)

http://AeroLectures.de, https://purl.org/AeroLectures

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Will there be an Electric Future in Comercial Flight?

- **Electrification in Transport**
- **A Bit of Physics**
- **Battery-Electric Aircraft**
- **Fuel Cells replace Batteries**
- **Outlook**


https://evtol.news/__media/Aircraft%20Directory%20Images/Joby%20S4/Joby-inflight.jpg





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Electrification of Transport

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Electrification of Transport:

Automotive:

- 120 years of electric vehicles
  - Lohner Porsche 1899
  - Plug-in 4WD Hybrid 1902
  - US Market Share up to 40%

Challenges:

- Battery-Electric Power Train
  - Battery
    - 400 – 800 V
    - 25 – 100 kWh
    - 150 – 600+ kg
    - ➢ **= 10…50 l Fuel**
- Alternative: Fuel Cells
  - High Range
  - Easy to refill
  - Expensive Fuel

Porsche Semper Vivus 1899



Porsche Mixte 1902 1902 Plug-In Hybrid „SUV“



Porsche Mission e 2015



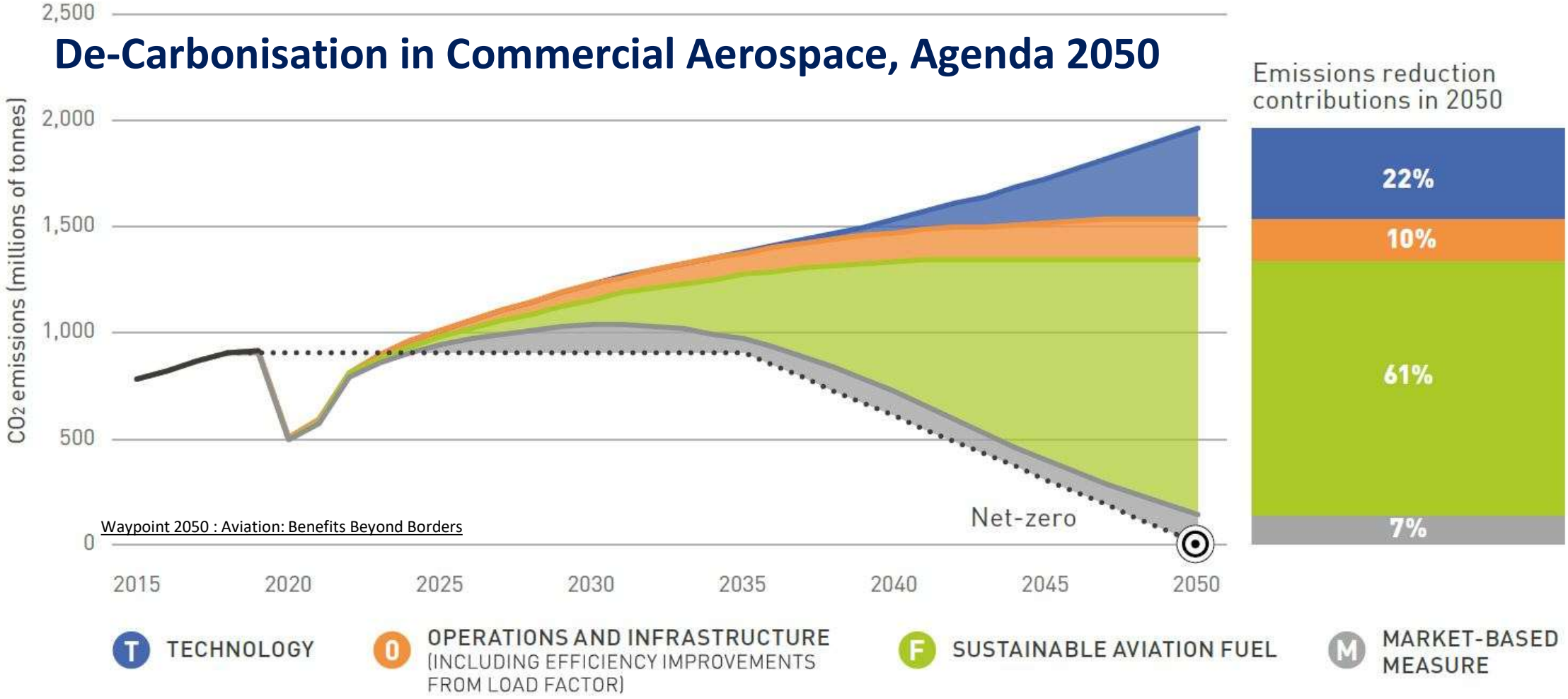


2020 Toyota Mirai Fuel Cell Hybrid

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Electrification of Transport:

Air Traffic and Climate Change



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Electrification in Transport:

Aerospace:



HB Brditschka MB-E1 **1973**

https://upload.wikimedia.org/wikipedia/commons/thumb/2/20/HB_Brditschka_HB_23_2400-1.JPG/250px-HB_Brditschka_HB_23_2400-1.JPG



Solar Impulse 2009

https://tse2.mm.bing.net/th?id=OIP.sggK_lgseVPZtr_ZnbhKywHaEk&pid=Api



DLR HY4

Von DLR, CC-BY 3.0, CC BY 3.0 de, https://commons.wikimedia.org/w/index.php?curid=51949225

50 Years ago: Start of Experimental-Electric-Aircraft

- **1973: 10HP Bosch-eMotor, NiCad Battery for 10min**
- **2009: 40.000km PV + Battery**
- **2016: 1000km Fuel Cell + Battery Hybrid**
- **2021: Speed-Record 620km/h**



Rolls-Royce Spirit of Innovation

https://im-efahrer.chip.de/files/rr-spirit-of-innovation-e-flugzeug-619e25774055b.jpg?imPolicy=lfOrientation&width=720&height=405&color=%23000000&hash=6074a1274988a10a18f774a13e59ca23e7bb2adee204

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Electrification in Transport:
Recent Development Projects:

- **Air Taxi:**
  - 2-4 PAX
  - TakeOff Weight 0,5…2 to
  - Range 20…50 km
  - Endurance < 0,5 hours
  - Size 8-10 m





More Range when using Wings

- **E-Aircraft fully electrical or hybrid**
  - 2-30 PAX
  - Range 50…500 km



- **Challenges:**
  - Safety
  - Weight and Range
  - Business Case

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A Bit of Physics

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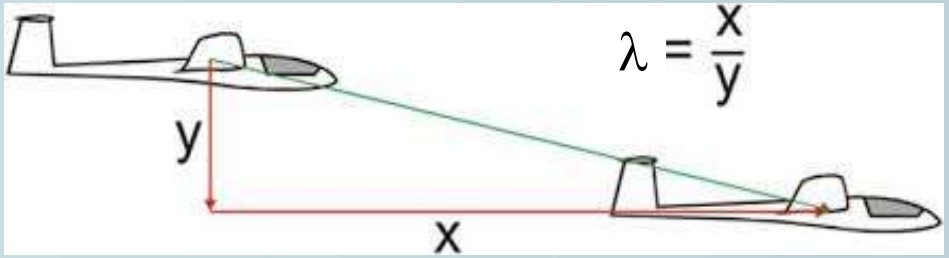
A Bit of Physics

… Glide Ratio, Energy

$$\textbf{Glide Ratio } \lambda = \frac{Lift}{Drag} = \frac{\textbf{Range } x}{\textbf{Loss of Altitude } y}$$

Sailplanes: $\lambda = 30 \ldots 70$ Helicopters $\lambda = 4 \ldots 8$

Commercial Aircraft: $\lambda = 15 \ldots 24$



https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&ved=2ahUKEwjM0JLG0fviAhXQDuwKHeF3CzUQjRx6BAgBEAU&url=http%3A%2F%2Fwww.mgow.ch%2Ferstflug_ewd_und_schwerpunkt.htm&psig=AOvVaw0RqE9mBLuVLnMTd9m_iqVa&ust=1561241251931775

$$\textbf{Energy Consumption } E = m \times g \times h$$

$$E = \frac{\textbf{Weight} \times \textbf{Range}}{\textbf{Glide Ratio } \lambda}$$



https://www.google.com/url?sa=i&url=https%3A%2F%2Fluftrettung.adac.de%2Fstationen%2F&psig=AOvVaw1zFl...FmklSQNTLeGEZ-sRj&ust=1650195809793000&source=images&cd=vfe&ved=0CAwQjRxqFwoTCKCnvpa5mPcCFQAAAAAdAAAAABAD



https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&ved=2ahUKEwjc6_fDh_3iAhXQfFAKHSveC9wQjRx6BAgBEAU&url=http%3A%2F%2Fwww.paradisi.de%2FFitness_und_Sport%2FLuftsport%2FSegelfliegen%2F&psig=AOvVaw22d1W6XzMACbk3Lh4N5TFf&ust=1561291824455510

Airbus $A330$:

$$\mathbf{E} = \frac{m \times g \times R}{\lambda} = \frac{240to \times g \times 12.000km}{20} = 400\,MWh$$

H = 600km equivalent altitude for glide





Fuel burn Pax Aircraft: 2-3 l/(pax*100km) @ 1000km/h

Fuel burn Car : 4-8 l/(1…4 pax pax*100km) @ 100km/h

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A Bit of Physics

… Range and Weight



https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.aircharterservice.de%2Finformationen-zu-flugzeugen%2Fgrossraumflugzeugen%2Fairbus-europe%2Fairbusa330-200&psig=AOvVaw0CNngALTIAMmsrRf4i8Cln_&ust=1650261242019000&source=images&cd=vfe&ved=0CAwQjRxqFwoTCLiu6K20mvcCFQAAAAAdAAAAABAM

Typical Long Range Aircraft:

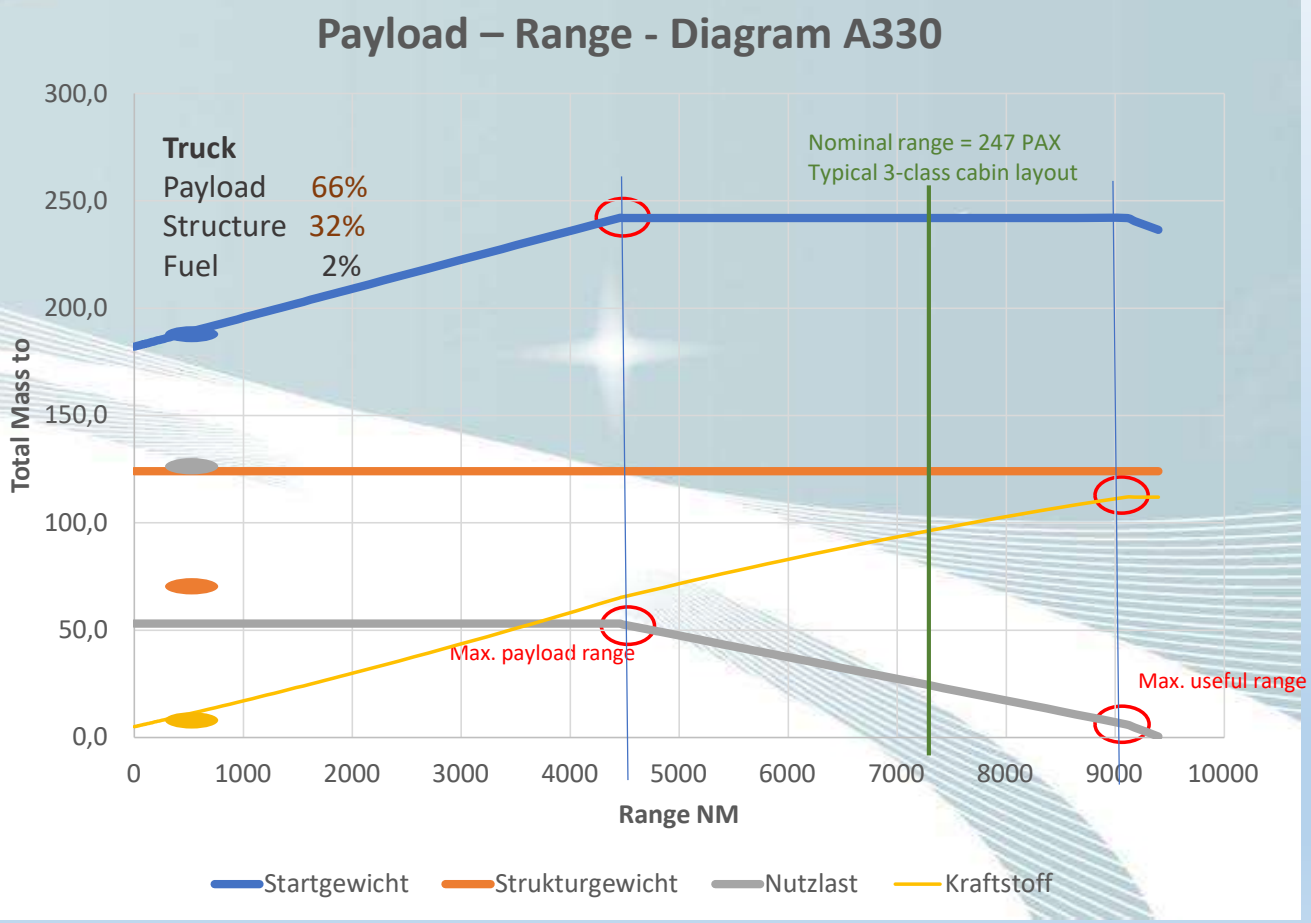
50% Structural Weight incl. Engine

40% Fuel

20% Payload

Airbus A330-200:

MTOW	242 to (100%)
Structural Weight OWE	124 to (51%)
Fuel Capacity	109 to (45%)
Payload Capacity	53 to (21%)
Nominal Range	7230 nm (13 tkm)



MTOW	Maximum Take Off Weight
OWE	Operational Weight Empty
nm	Nautical Mile= 1,852km

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Battery-Electric Aircraft

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Battery-Electric Aircraft

What about Electric Drives?



Tesla Model S

500 kW / 236 kg

incl. 79 kg Gear Box

2,1 kW/kg



https://www.aerosieger.de/images/news_picupload/pic_sid4867-2-norm.jpg

Siemens 2015

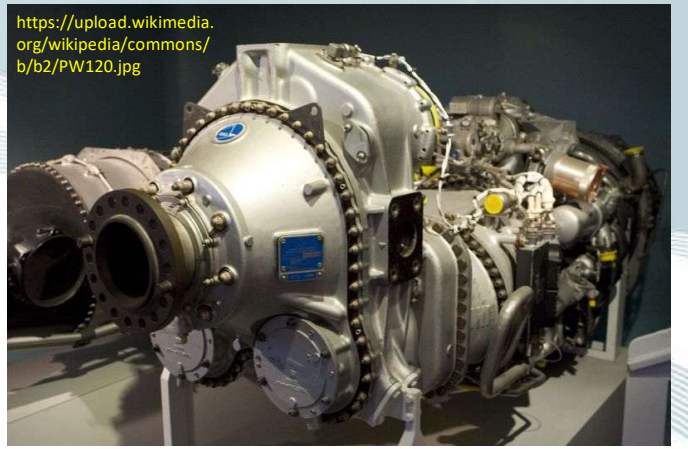
Technology Demonstrator

260 kW / 2.500 Upm

5 kW/kg



https://www.bing.com/images/blob?bcid=qGa.nleSs-kHezrDoOYJXJs9Qapm.....8s



https://upload.wikimedia.org/wikipedia/commons/b/b2/PW120.jpg

ATR 72-600 (72PAX)

2 x 2045 kW / 480 kg

incl. 180 kg Gear Box

4,6 kW/kg

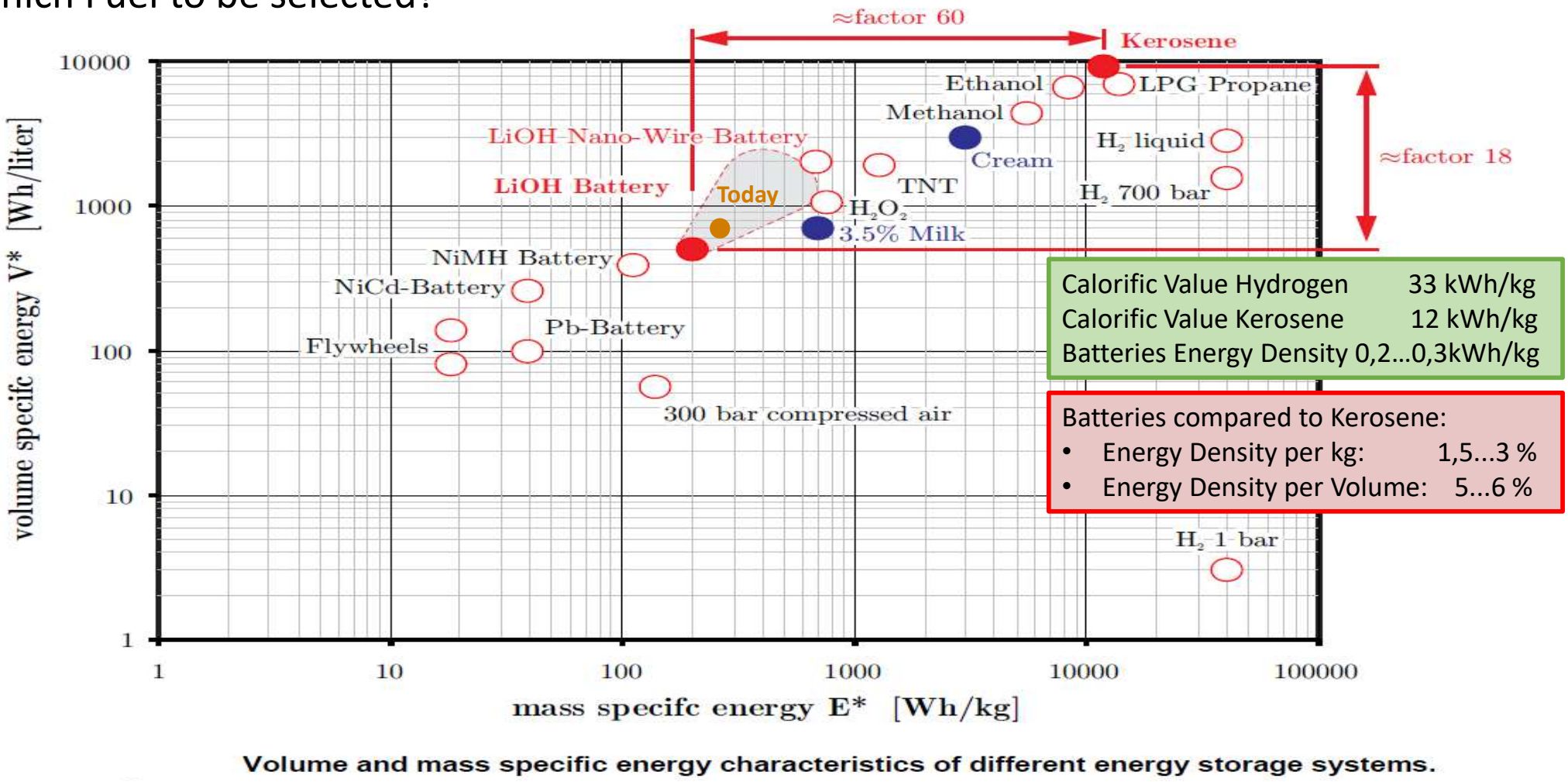
Required Range of Engine Power in Aviation: 5…20 kW/kg at 2…50 MW

State of the Art Aerospace E-Drives: 1…10 kW/kg at 0,1…2,5 MW

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Battery-Electric Aircraft

Which Fuel to be selected?



Volume and mass specific energy characteristics of different energy storage systems.

Calorific Value Hydrogen	33 kWh/kg
Calorific Value Kerosene	12 kWh/kg
Batteries Energy Density	0,2…0,3kWh/kg

Batteries compared to Kerosene:

- Energy Density per kg: 1,5...3 %
- Energy Density per Volume: 5...6 %

DLR: Electric Flight and Propulsion STO-MP-AVT-209

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Battery-Electric Aircraft

Elektrical Power Train for Airbus A330e



A330-200:

Typical Mission in 3-class Layout:

7200nm (13.000km) 247 PAX Munich - Lima, Peru

~ 2,7 l / (100km*PAX)

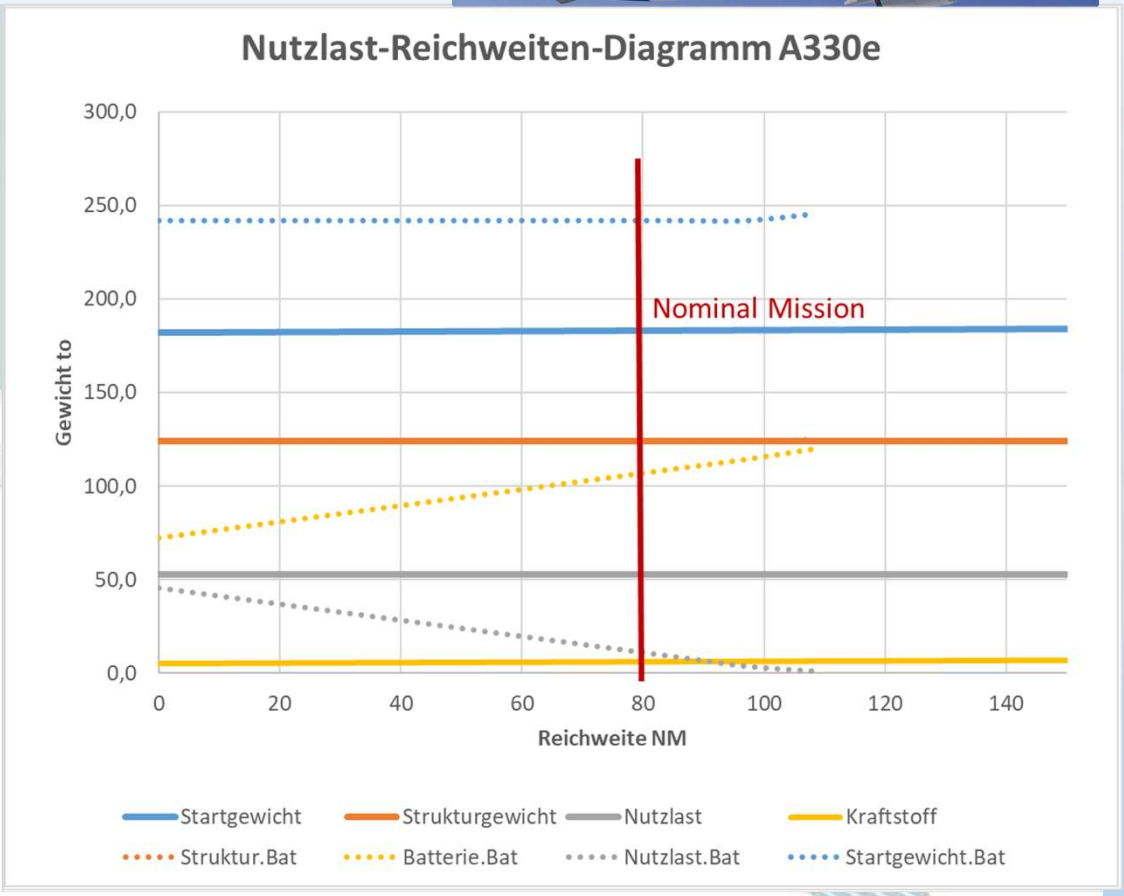
Calorific Value Kerosin	12.000 Wh/kg	**50x**
Energy Density Li-Ion Battery per Module (optimistic)	240 Wh/kg	**1x**
Efficiency of Turbine Power Train	45%	**22x**

Maximum electrical Mission:

80nm (150km) 100 PAX Munich – Linz, Austria

Battery 109 to total = 240 kg / (100km*PAX):

- **30to (Cruise Flight)**
- **80to !! Reserves (150nm + 45min)**



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Battery-Electric Aircraft

Design for Electrification: Propeller or Fan?



Pratt & Whitney 127F
24,7 kN TakeOff Thrust
D-Prop 3,93 m



Honeywell ALF 500
25 kN TakeOff Thrust
D-Fan 0,91 m

TakeOff Thrust F and Power P

$F = \dot{m}_{in} * \Delta v$ $\quad P = \frac{\dot{m}_{in}}{2} * (v_{Outflow}^2 - v_{TakeOff}^2)$

Comparrison Propeller versus Turbofan

v_Inflow = v_TakeOff + $\frac{1}{2}\Delta v$, v_TakeOff = 69,4 m/s (250km/h)

Propeller	**Turbofan**
$\dot{m}_{in} = 1185\ kg/s$	$\dot{m}_{in} = 131\ kg/s$
$\Delta v_{Outflow} = \frac{F}{\dot{m}_{in}}$ = 21 m/s	$\Delta v_{Outflow} = \frac{F}{\dot{m}_{in}}$ = 189 m/s
v_{Inflow} = 80 m/s	v_{Inflow} = 164 m/s
$v_{Outflow}$ = 90 m/s (360 km/h)	$v_{Outflow}$ = 258 m/s (929 km/h)
P = 1.973 kW	P = 4.044 kW

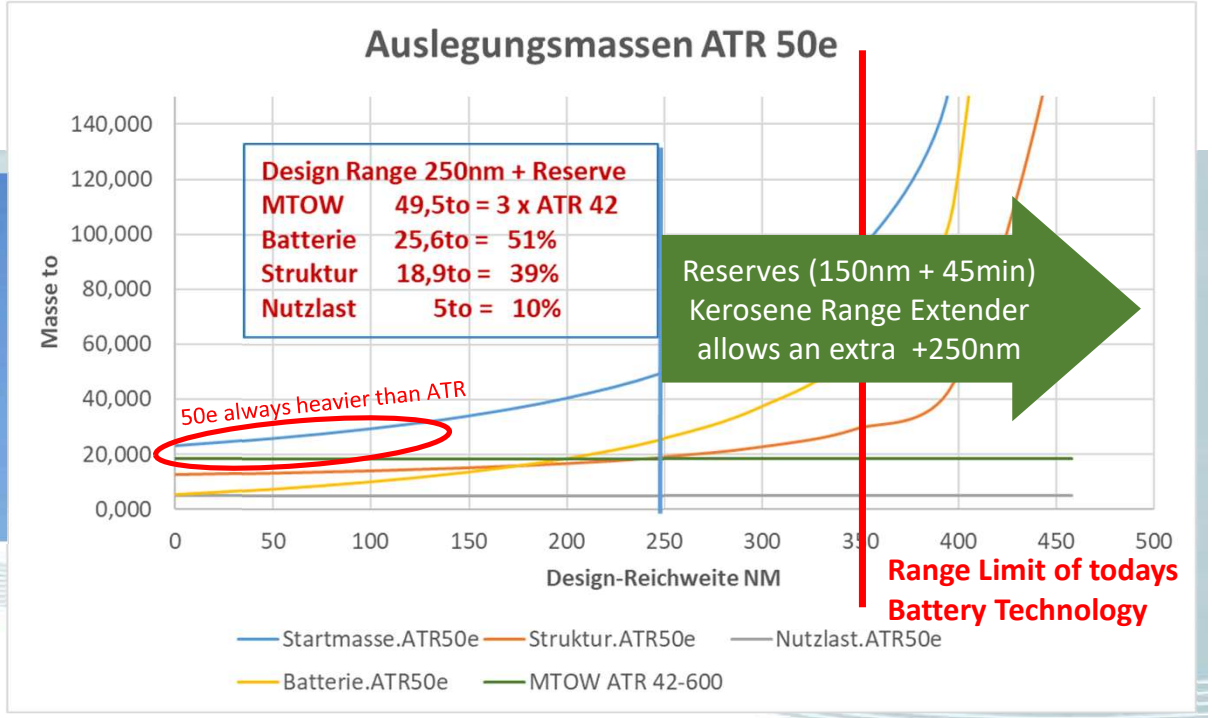
- Propellers need much less power in TakeOff but are limited to 500…700 km/h cruise speed
- Turbofans lose a lot of thrust at altitude due to air density but convince by very high TakeOff thrust

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Battery-Electric Aircraft

Design of an Electric Aircraft ATR 50e





ATR 42-500:

MTOW	18,6 to (100%)
Structural Mass OWE	10,1 to (54%)
Max. Fuel	4,5 to (24%)
Max. Payload	5,2 to (28%)
Typ. Layout	50 Pax
Nominal Range (1300km)	700 nm
Maximale Range (3100km)	1700 nm

Design Equation (Prof. Torenbeek 1986):

$$MTOW = OWE + Payload + EnergyWeight$$

$$EnergyWeight = \frac{(Range + Reserves) * MTOW * g}{\lambda} * spec.Weight.Batt.$$

$$OWE = 1{,}25 * Payload + \mathbf{0{,}24} * MTOW + 0{,}5\ to$$

MTOW Maximum Take Off Weight
OWE Operational Weight Empty
nm Nautische Meile= 1,852km

12.06.2025

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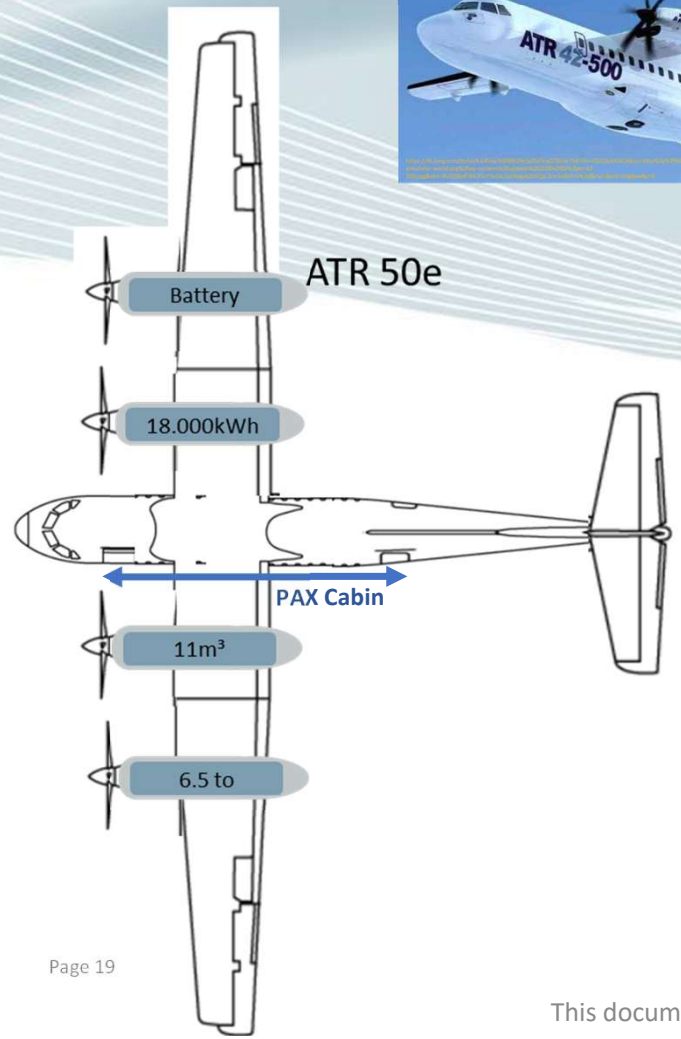
Battery-Electric Aircraft

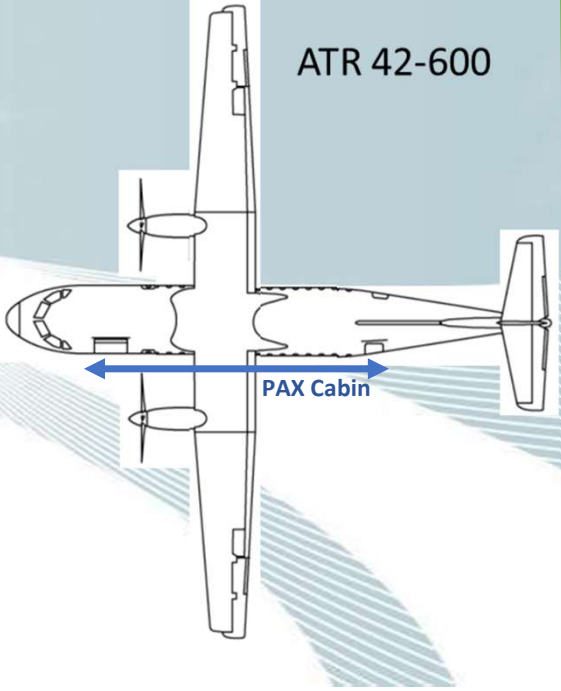
Economy of Battery-Electric Aircraft - ATR 50e (250nm)

ATR42 – ATR 50e - 250nm Design Range

	ATR42	ATR50e
MTOW kg	18.600	49.450 x2,8
OWE w/o batteries kg	11.700	18.860
Fuel 460km	716,6	25.590 x35
Aircraft Price M€	**9,7**	**16,6…30,0**
Ticket Price	**100%**	**190%…390%**







MTOW Maximum Take Off Weight
OWE Operational Weight Empty
nm Nautical Mile= 1,852km

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Battery-Electric Aircraft

Project in Produktion

- **Challenges:**
  - **Weight**
  - **Cost**
  - **Business Model**



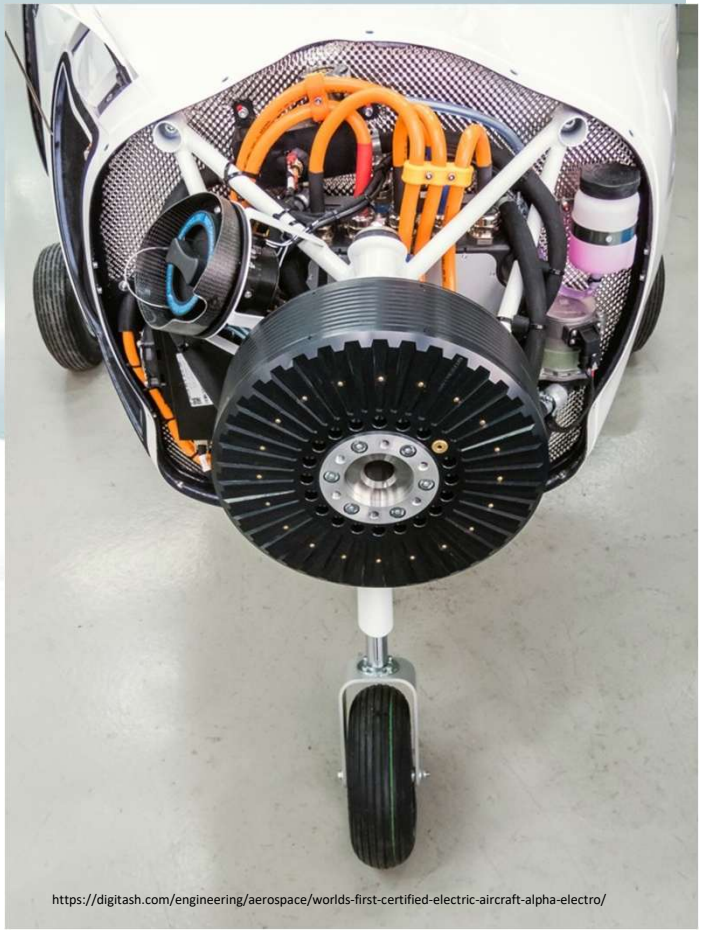
https://www.aerobuzz.fr/wp-content/uploads/2018/04/AERO-electro-Pipistrel-Alpha--560x374.jpg



https://www.aopa.org/-/media/images/legacy/aopa/pilot/1510p/1510p_pipi_001.jpg?mw=1200&mh=675&as=1&hash=051F772C2FC45B4FA0B8F8BD2BDFAE101E7DF151

Pipistrel: Slowakei,
Supplier of Ultra Light Aircraft
Alpha ist an 80 hp Trainer

E-Version (Trainer)
Flight Time 60min
+ 30min Reserves
Powerplant 50kW
Battery 20kWh (>100kg)



https://digitash.com/engineering/aerospace/worlds-first-certified-electric-aircraft-alpha-electro/

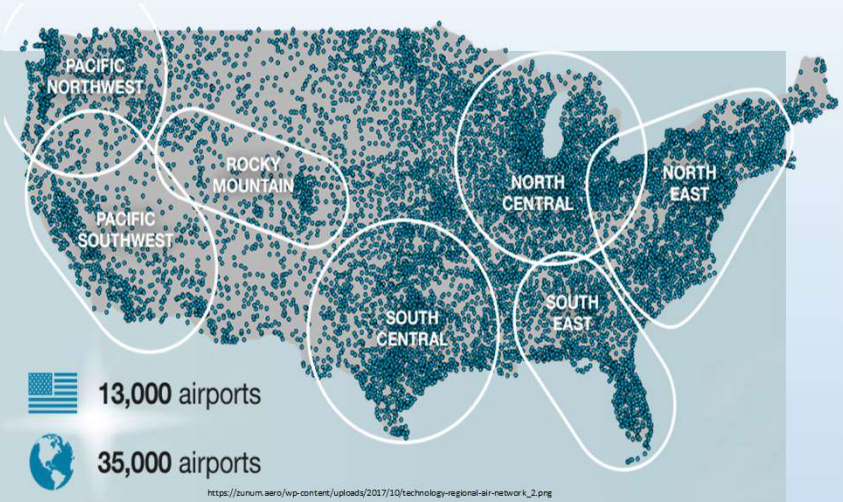
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Battery-Electric Aircraft

Promising Project: Eviation Alice

- Commuter Shuttle
- Challenges:
  - Technology Readiness
  - Weight and Cost
  - Performance / Battery
  - Business Model







Eviation: Start-Up from Israel and USA
Alice: Short Range Elektro Commuter
9 Passengers (~1,1to / 13% of MTOW)
Range 250 nm (+ Reserves)
250 kn (460 km/h)
8,4 to MTOW, 4,8 to of Batteries (CS-23)
2 x 700kW Engines
200 Wh/kg Battery
~ 57% of Aircraft Mass in Batteries
~ 36% (3 to) Structural Mass

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Battery-Electric Aircraft

CS-25 Commercial Aircraft - Heart ES-30 – in Project State

Initial Design ES-19:

- **4 Autonomes Engine Nacelles with**
  - **Electric Drive**
  - **Battery**
  - **Charging Port**

Today's Design Status ES-30:

- **Experienced Airframe Manufacturer on Board**
- **Batteries moved into Fuselage and Wings**
- **30 PAX instead of 19**

- **2 Turboprop Engines in outer Nacelles for**
  - **Better Range**
  - **Lower Empty Weight**



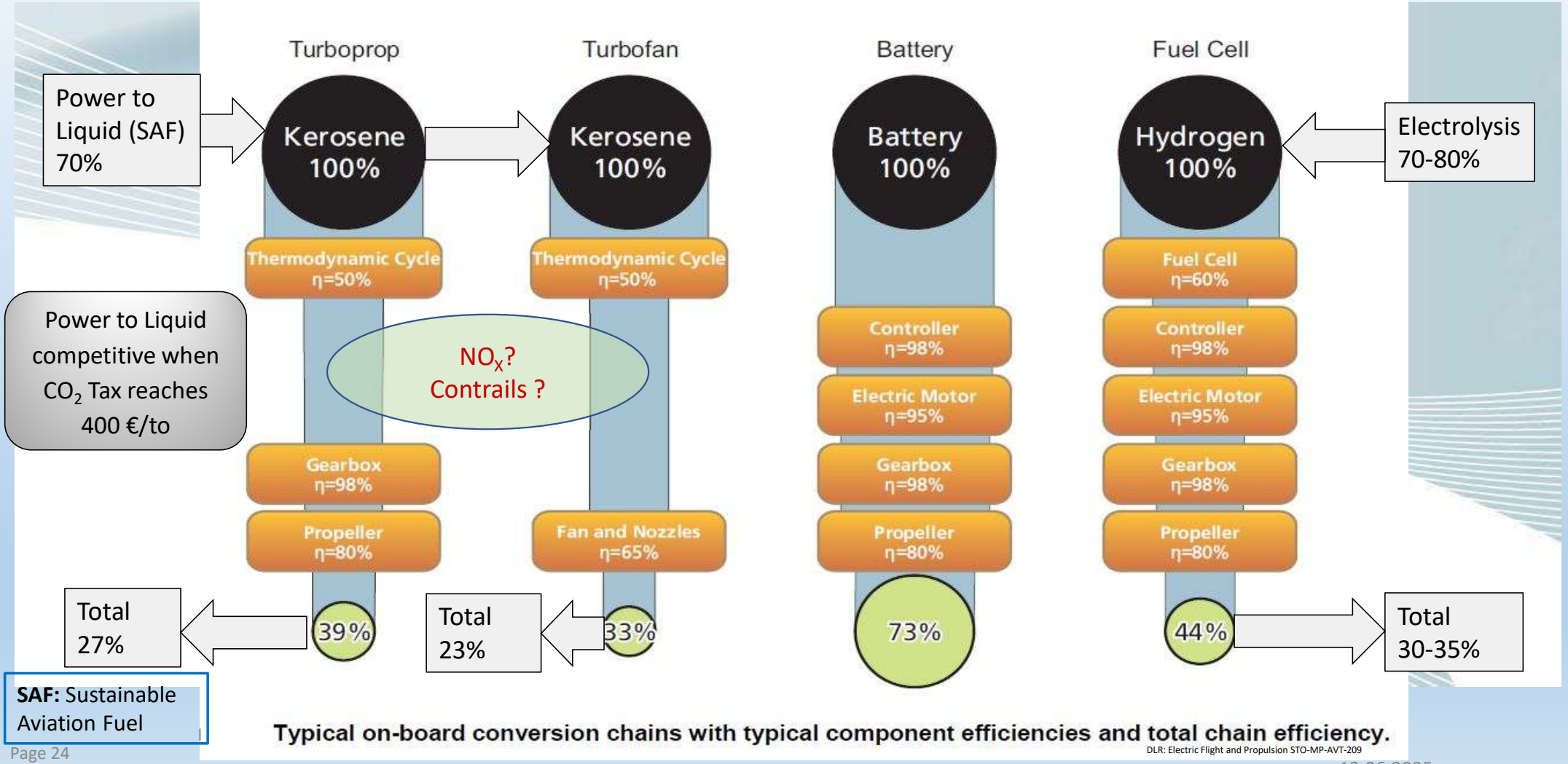
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Fuel Cells to replace Batteries

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Fuel Cells replace Batteries

Chain of Efficiencies in Power Train – Competing Concepts



Typical on-board conversion chains with typical component efficiencies and total chain efficiency.

DLR: Electric Flight and Propulsion STO-MP-AVT-209

SAF: Sustainable Aerospace Fuel

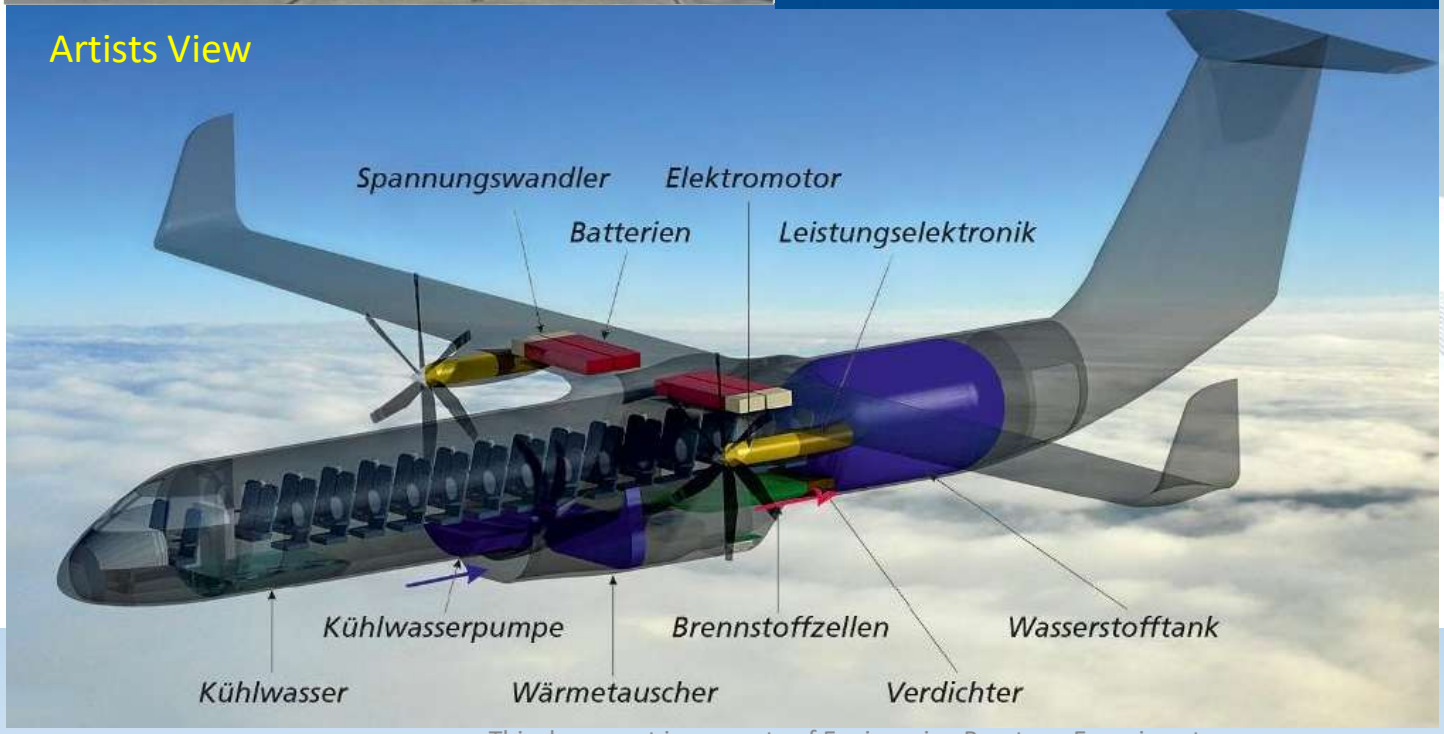
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Fuel Cells replace Batteries

The Fuel Cell Vision







Hydrogen:

- High energy density
- 33.000Wh/kg (Calorific Value)
- Environmentally friendly

Fuel Cell

- Batteries in TakeOff + Climb?

Challenges:

- LH_2Volumen
  - 3 kWh/l (Kerosene 9 kWh/l)
- Cryogenic tanks (2 kg/kgH_2)
- Fuel cell weight (1-2kW/kg)
- Drag (Cooling+Weight+Volume)
- Fuel cost

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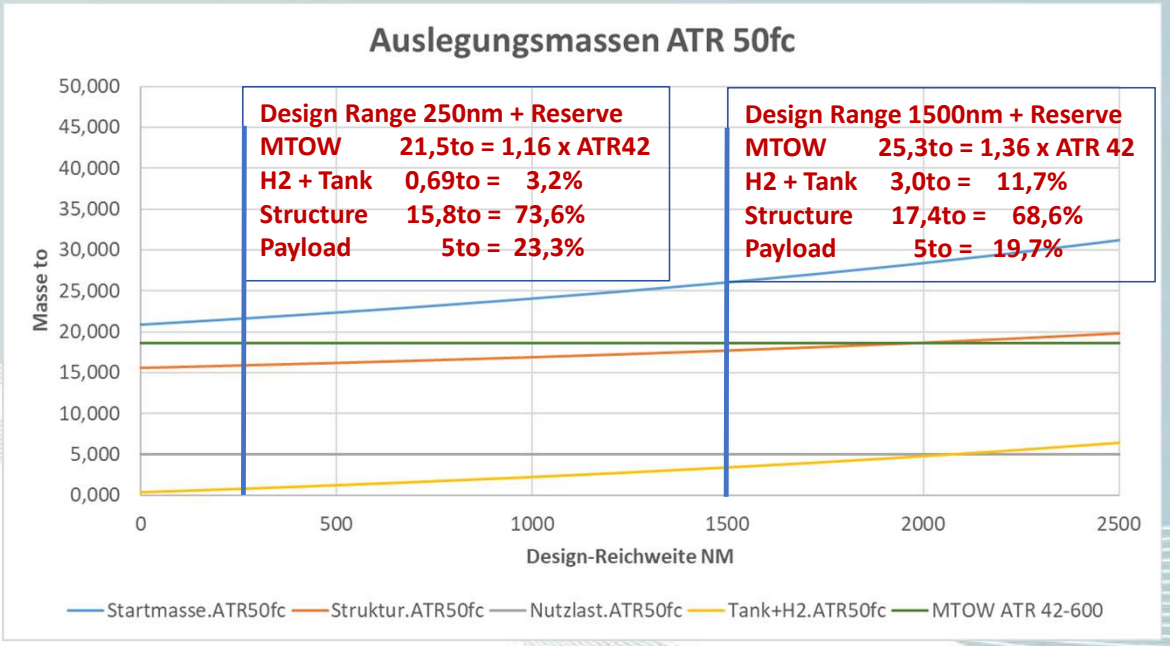
https://www.youtube.com/watch?v=TCELVvDChYk
https://www.youtube.com/watch?v=1iRSN0oTeFc&t=21s

Fuel Cells replace Batteries

Fuel Cell Electric Engine for the ATR 50fc



Calorific Value Kerosene	12.000 Wh/kg	1x
Calorific Value Hydrogen	33.000 Wh/kg	0,8x
Mass Cryo-Tank	2,2 kg/kgH_2	
Mass FC – Power Train	2 kg/kW	3x



Fuel Cell Mission:

1500nm (2800km) 50 PAX
Munich – Antalya, Turkey
H2 Consumption ~ 950 kg H_2
(instead of 2000kg Kerosene)

Design Equation (Prof. Torenbeek 1986):

$$MTOW = OWE + Payload + EnergyWeight$$

$$EnergyWeight = \frac{(R + Reserves) * MTOW * g}{\lambda} * spec.Bat.Weight$$

+70%

$$OWE = 1{,}25 * Payload + (0{,}24 + \mathbf{0{,}17}) * MTOW + 0{,}5\ to$$

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Fuel Cells replace Batteries

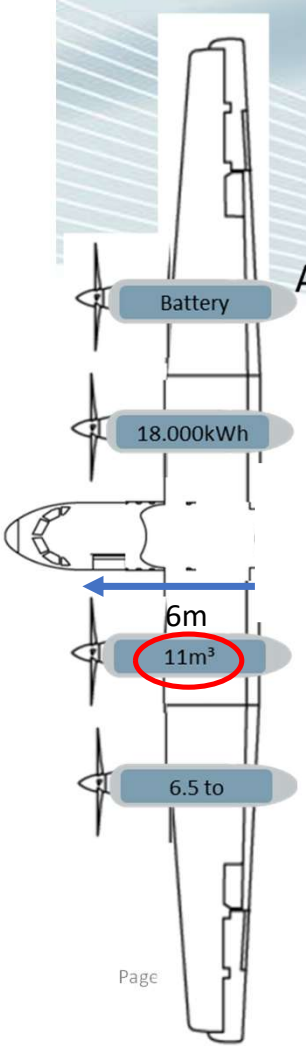
Comparing Design and Economics:

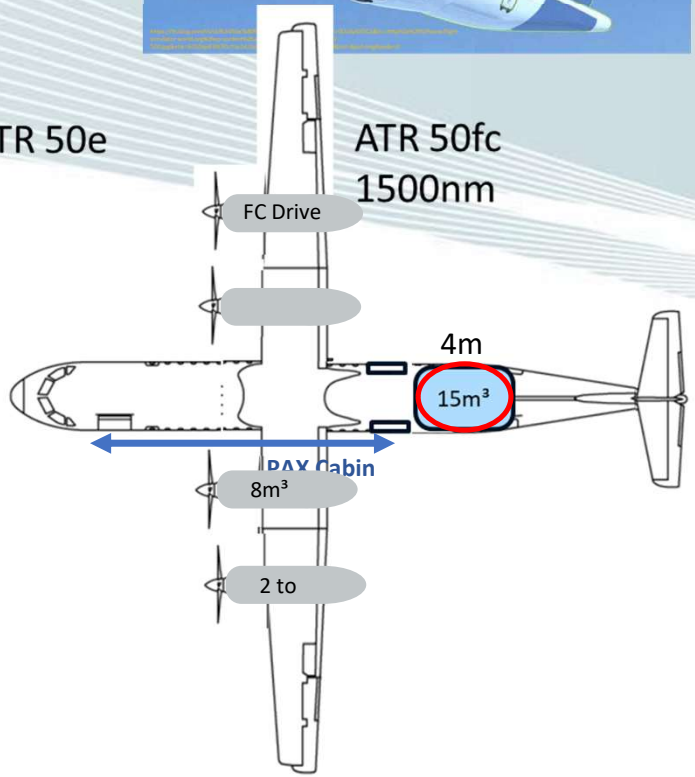
ATR 50fc and ATR 50e vs. ATR 42 (250nm / 1500nm)

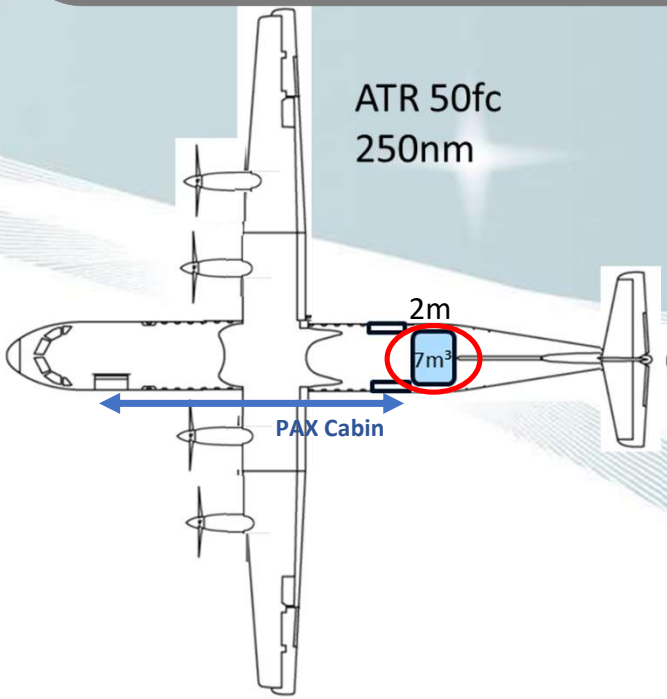
Mass and Cost: ATR42 – ATR 50e – ATR 50fc-250 / -1500

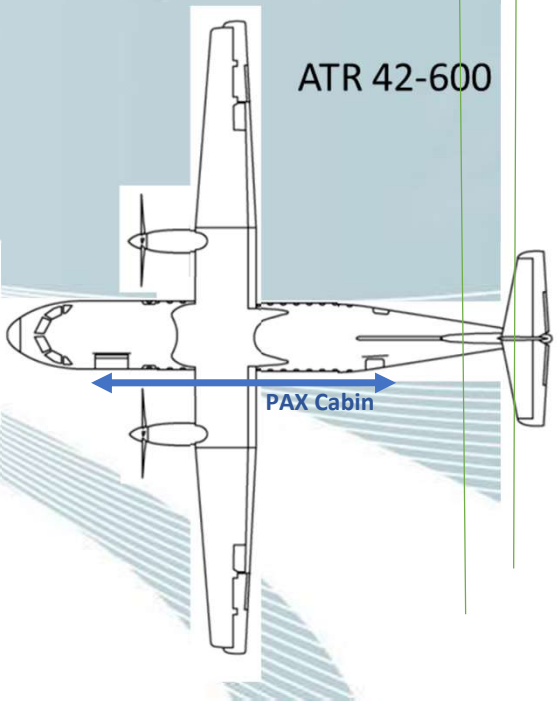
	ATR 42	ATR 50e	ATR 50fc
MTOW kg	18.600	49.450	21.500 / 25.350 +16 / 36%
OWE w/o „energy“ kg	11.700	18.860	17.390 +50%
Energy 250/1500nm kg	716 / 2.610	25.590/--	**750** / **3.310** incl.Tank
Aircraft Price M€	**9,7**	**16…30**	**8,7…11,4**
Ticket Price	**100%**	**150%…260%**	**104%…128%**











MTOW Maximum Take Off Weight
OWE Operational Weight Empty
nm Nautical Mile= 1,852km

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Outlook

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Outlook

- **Electric Aircraft Business remains extremely challenging on**
  - Economics
  - Technology Readiness
  - Network Size (Range)
- **What will we see?**
  - **Bigger Aircraft:**
    - eFuels (SAF) → Weight/Range
  - **Regional Routes:**
    - Fuel Cell Prop + LH_2
    - Hybrid Concepts (Battery + SAF-Turboprop)
  - **Ultra short range / UAM:**
    - Battery-Electric-eVToL / Wing


Pipistrel Alpha Electro







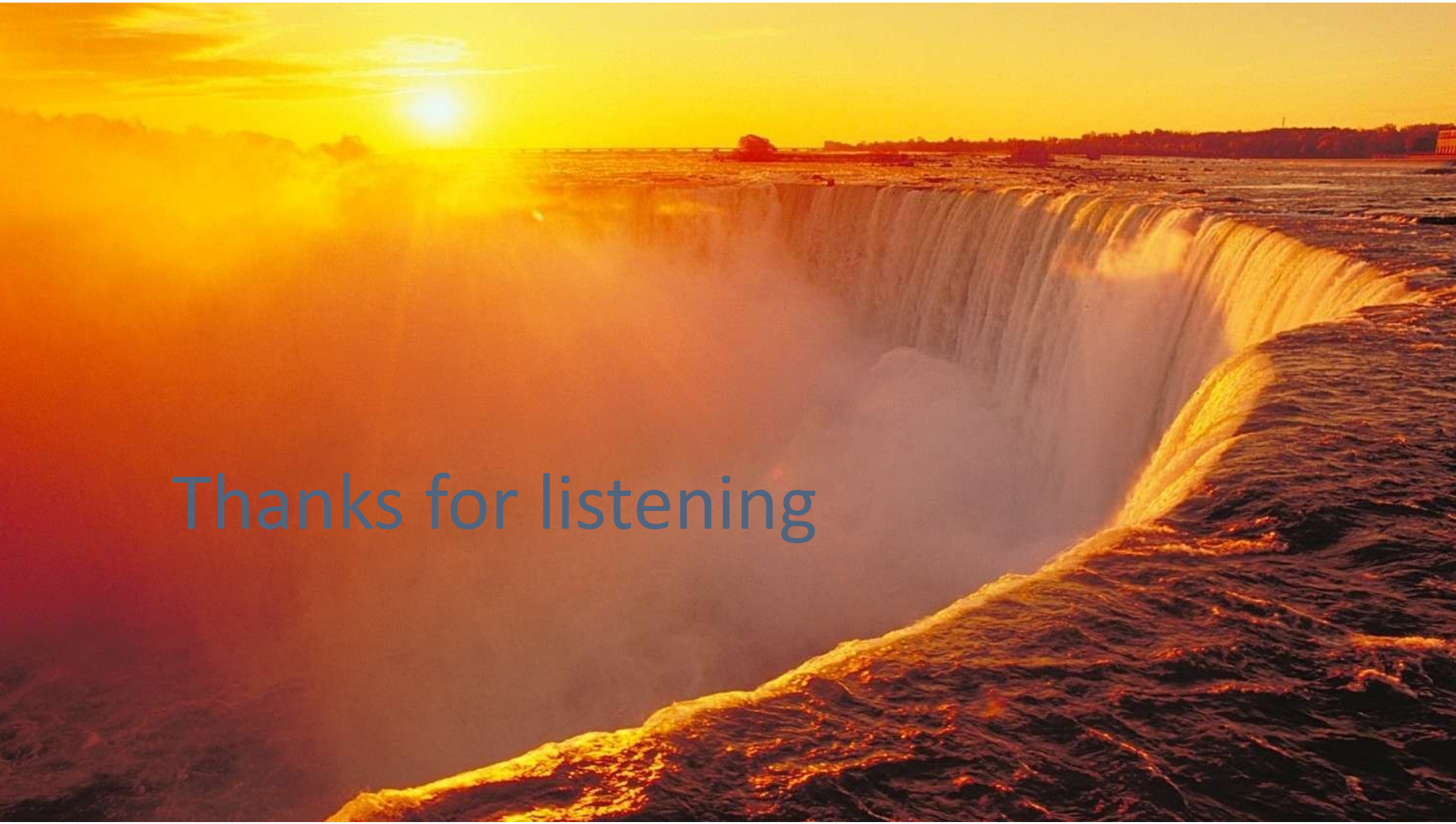




UAM: Urban Air Mobility

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12.06.2025


Thanks for listening