Electric and Hybrid-Electric Aircraft:

A pragmatic view

CEC/ICMC Conference 2019, Plenary Talk
23.07.2019 – Connecticut Convention Center

Dr. Mykhaylo Filipenko
Siemens AG – Corporate Technology – eAircraft

A glimpse into the future of transportation

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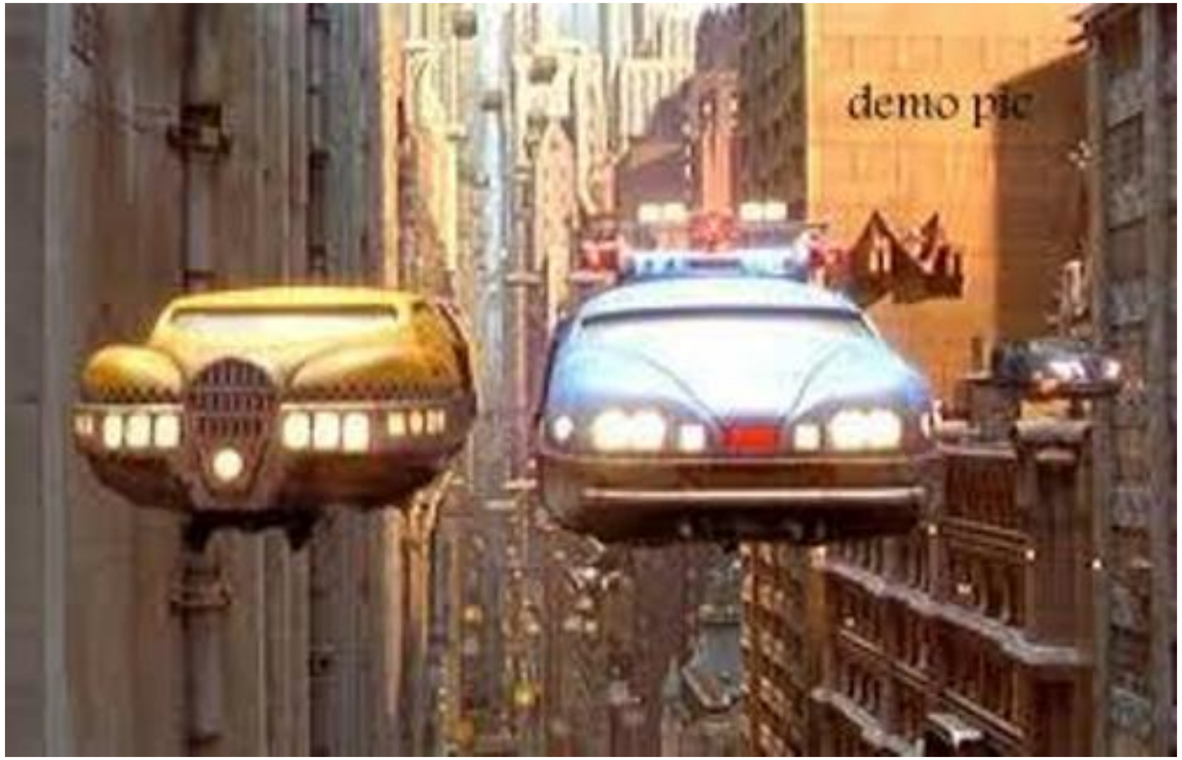

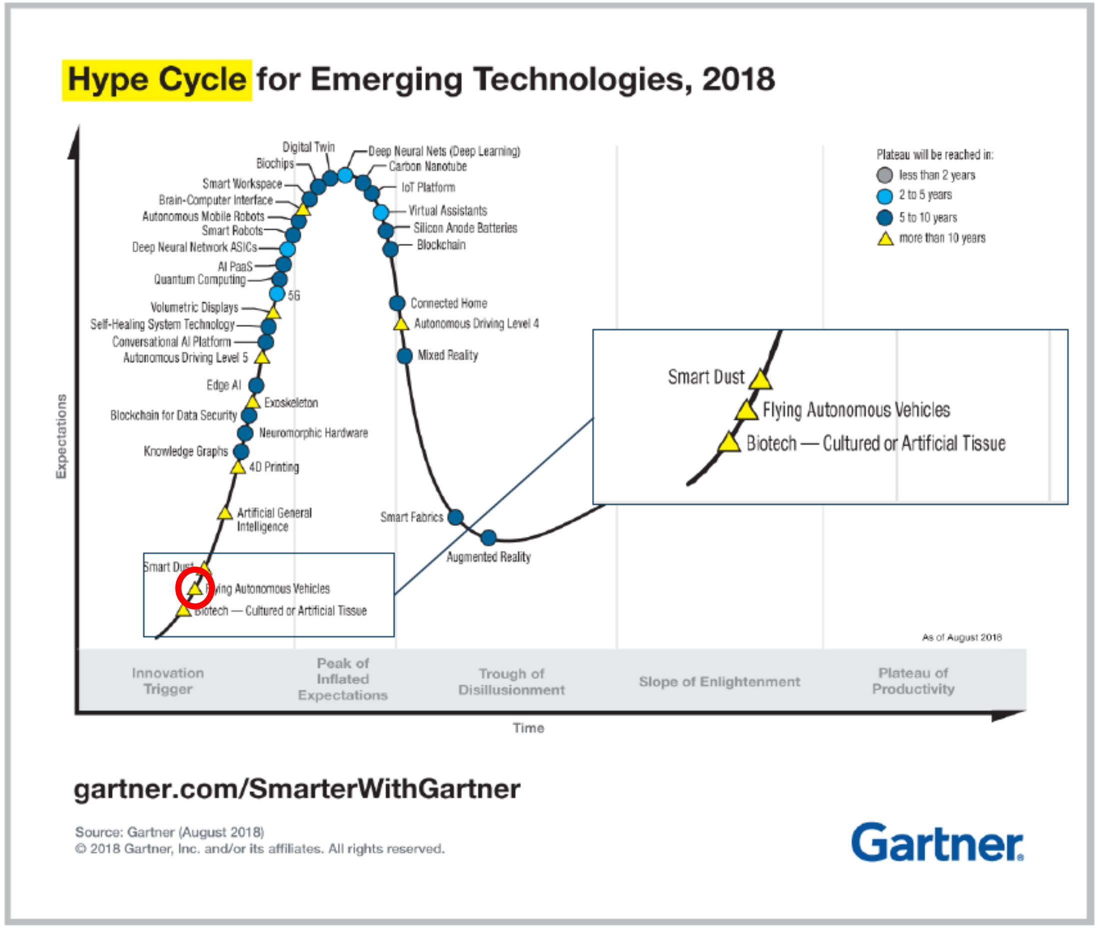

An Episode of Mythbusters

Focus Topic: Electric Aviation

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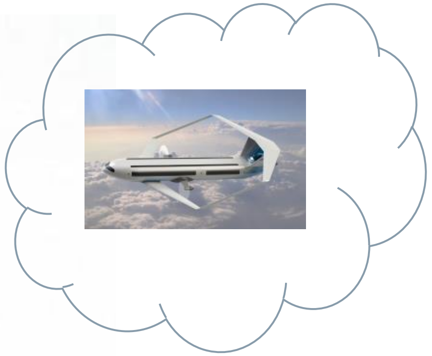

Agenda

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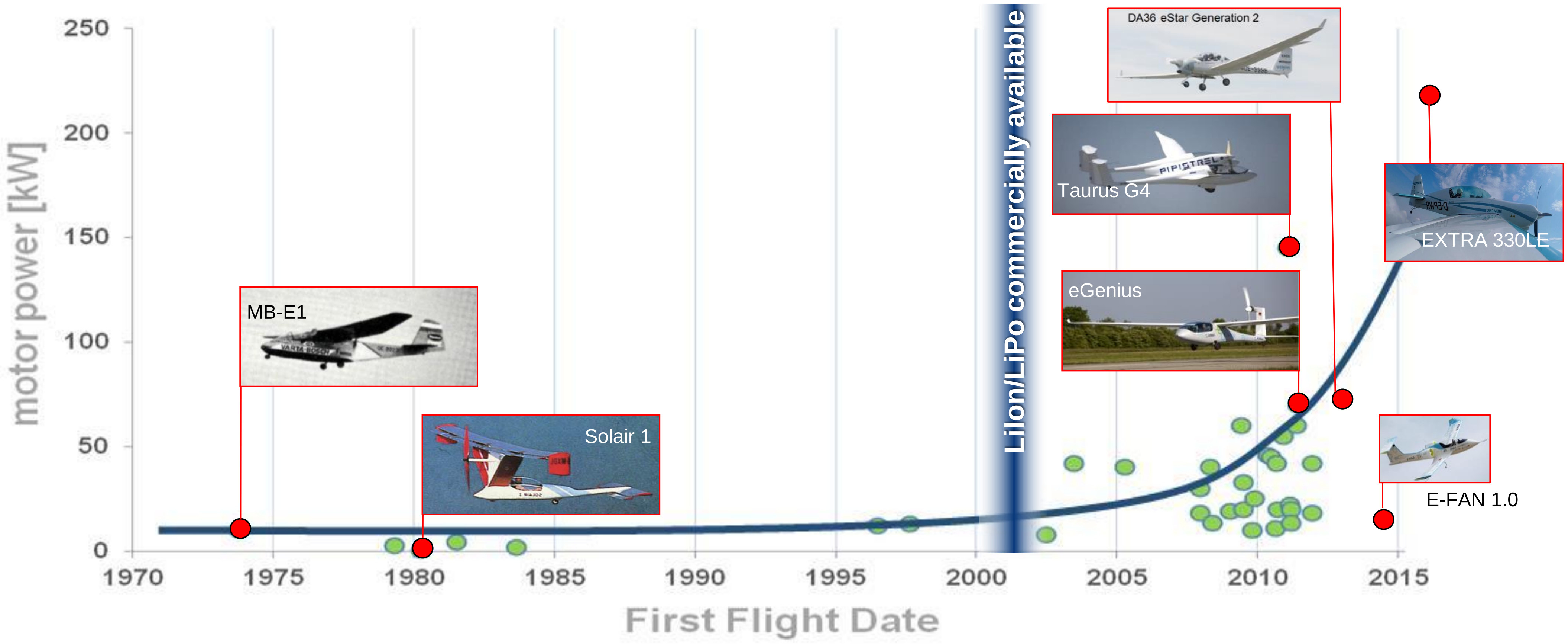
I. (Hybrid-)electric flight (in a nutshell)

II. Mythbusters: Particular Topics

III. Should we invest into (hybrid-)electric?



250
200
150
100
50
0
motor power [kW]
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
First Flight Date
LiIon/LiPo commercially available
MB-E1
Solair 1
DA36 eStar Generation 2
Taurus G4
eGenius
EXTRA 330LE
E-FAN 1.0

Siemens eAicraft flight test history

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Maiden flights of the DA36 e-Star, world's first hybrid-electric aircraft, and improved eStar 2, with Airbus and Diamond Aircraft

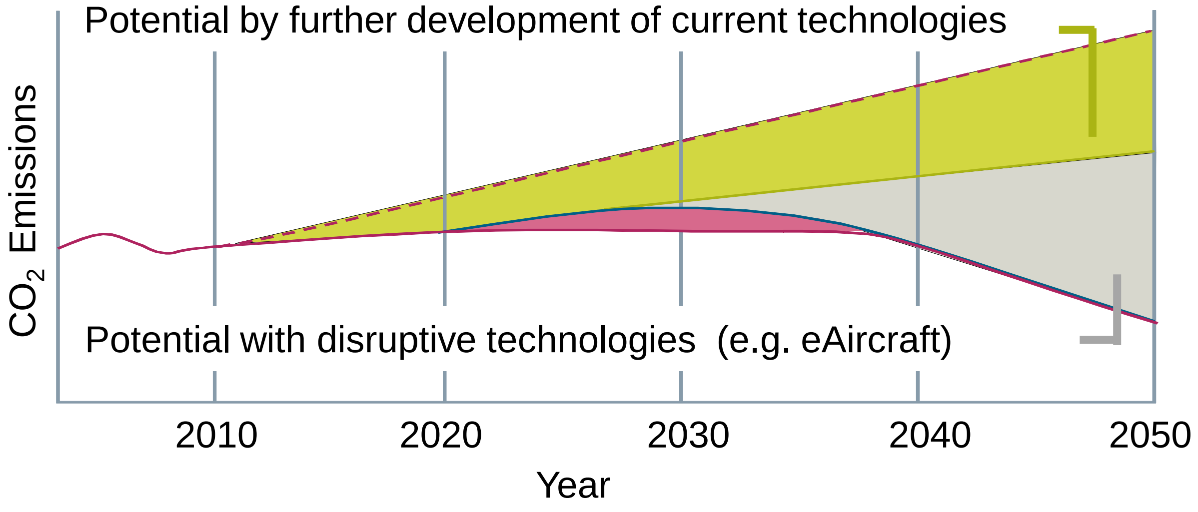
Maiden flight of the record propulsion system SP260D in the Extra 330LE

Maiden flight of the SP70D in the Magnus eFusion

Maiden flight of the world's first two engined serial-hybrid propulsion system

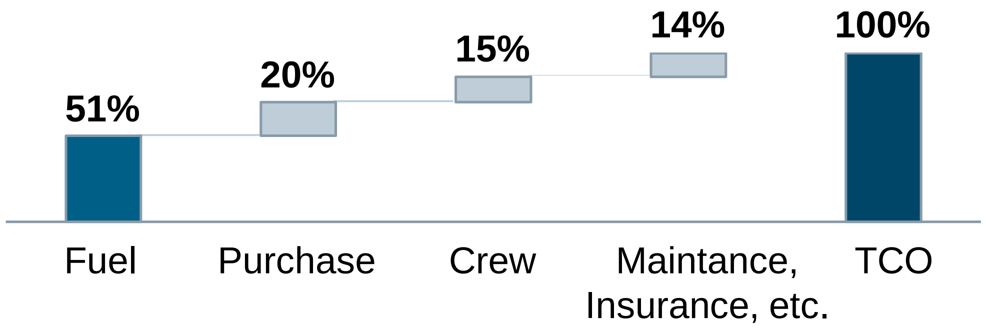
Why do we want to fly electrically?

ACARE 2050 goals can only be achieved with disruptive concepts[1)]



→ "Flight-path 2050" of EU requires 90 % reduction of NOx/CO2 emissions and 75 % noise emissions

Total cost of ownership (Bsp.: Boeing 737-800)[)1]

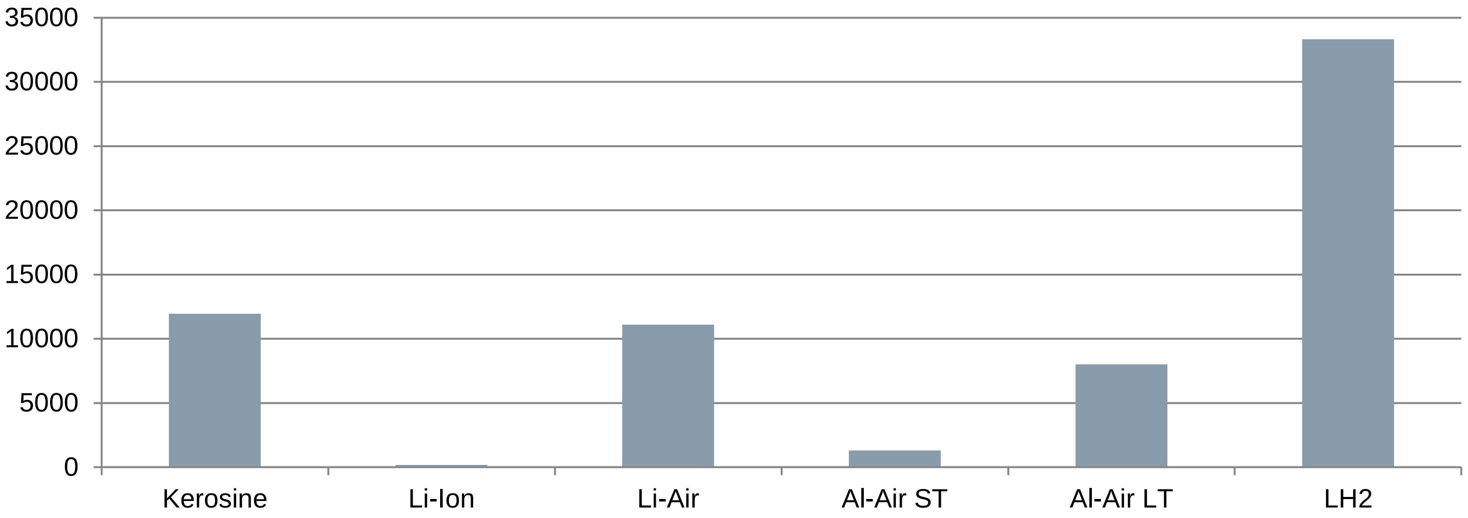


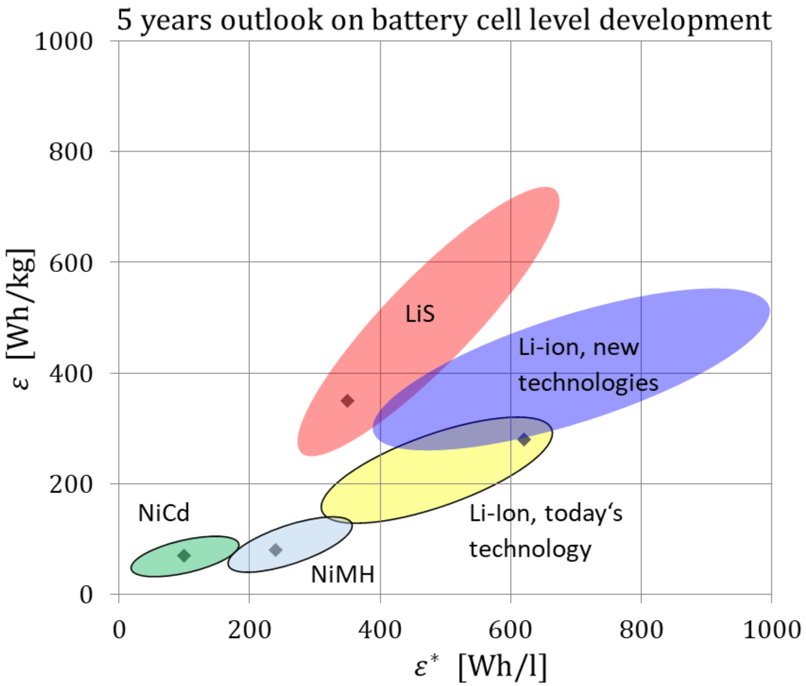
→ Fuel is a main cost driver

* IATA technology roadmap, June 2013
** eAir: Market studies

Challenge One – Battery

Energy Density of Various Energy Sources in kWh/kg





Data source: Sion Power

PHINERGY

Hybrid Electric Propulsion System

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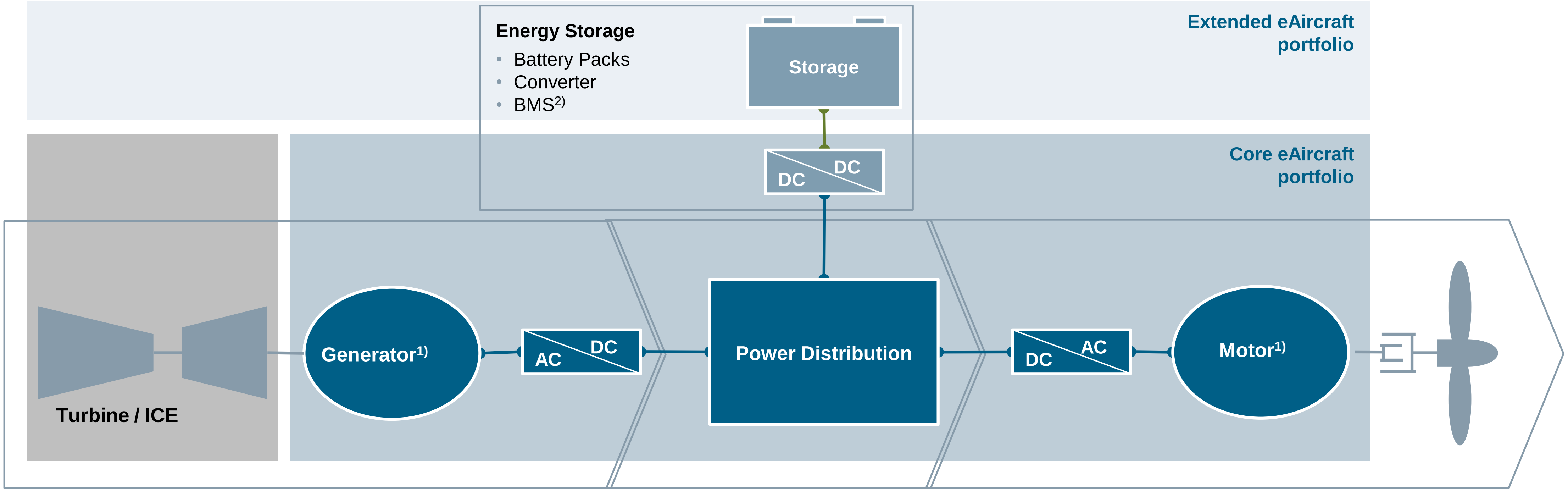

Power Generation
- Generator
- Inverter
- Controller
- Turbine/ICE[3)]

Power Distribution
- Circuit Breaker
- Switches
- Cables
- Connectors

Propulsion Unit
- Motor
- Inverter
- Propeller
- Gearbox

Propulsion System

1) E-machines are capable to fulfill “power generation” and/or “propulsion” depending on e.g. mission profile, requirements and/or mode of operation, 2) Battery Management System (BMS), 3) Internal Combustion Engine (ICE)

Agenda

I. (Hybrid-)electric flight (in a nutshell)

II. Mythbusters: Particular Topics

III. Should we invest into (hybrid-)electric?

Myth 1:
“A hybrid-electric A320 is a good airplane”

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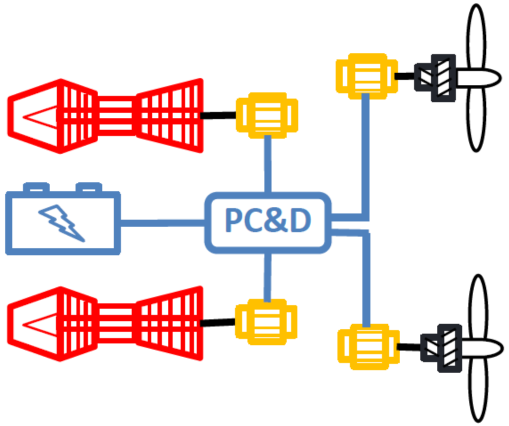

Keep A320 Design + “Replace turbine with hybrid-electric drive train” = “Not a good concept”

*Images taken from **G. Atanasov**: „Energy Efficient Hybrid Propulsion Concept for Twin Turboprop Aircraft“

Hybrid Electric Propulsion System vs. Conventional

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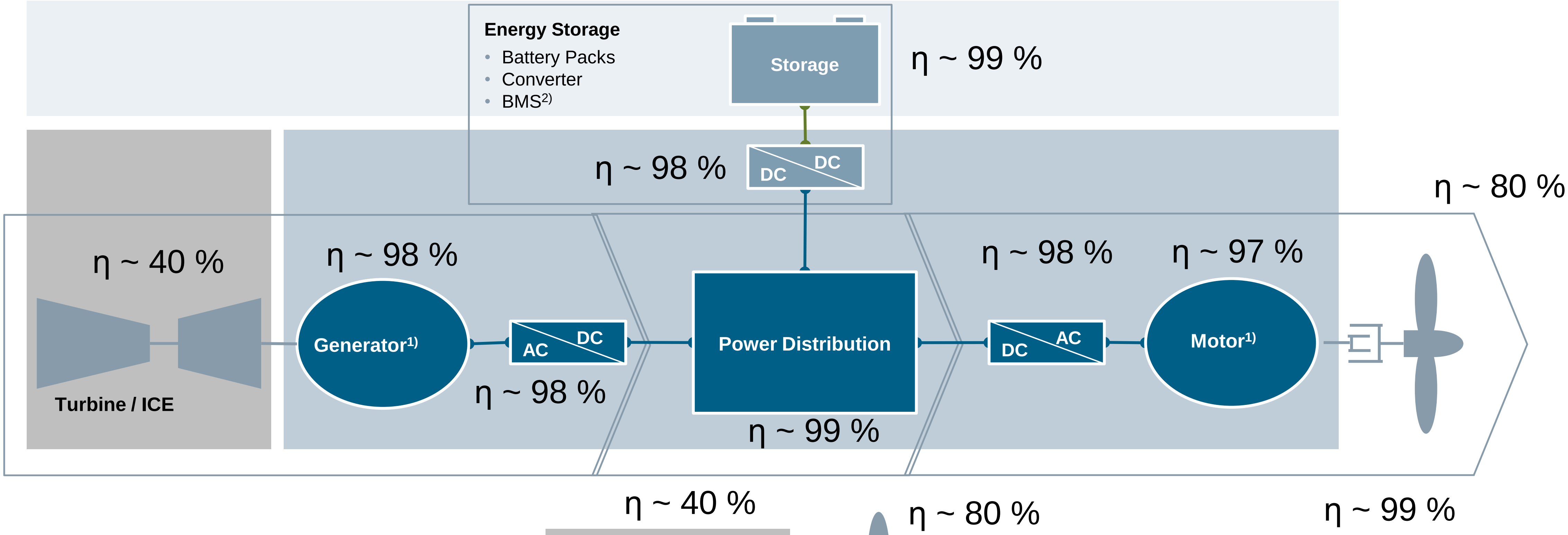
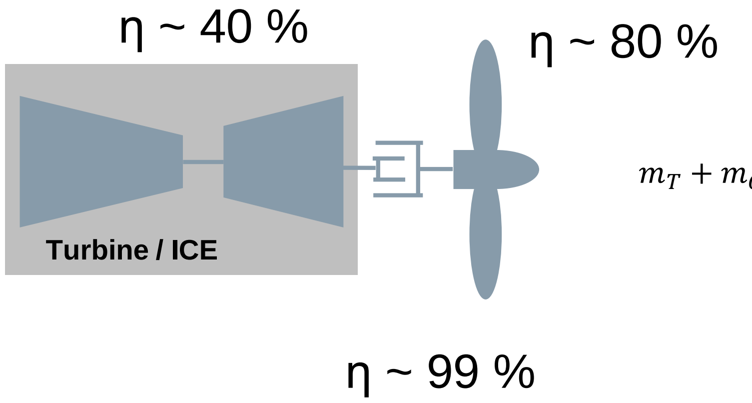
HEPS



Conventional

$$\eta_T \cdot \eta_G \cdot \eta_P \cdot \prod_e \eta_e < \eta_T \cdot \eta_G \cdot \eta_P$$



$$m_T + m_G + m_P + \sum_e m_e > m_T + m_G + m_P$$

Myth 2:
"We can have on optimized turbine operation point"

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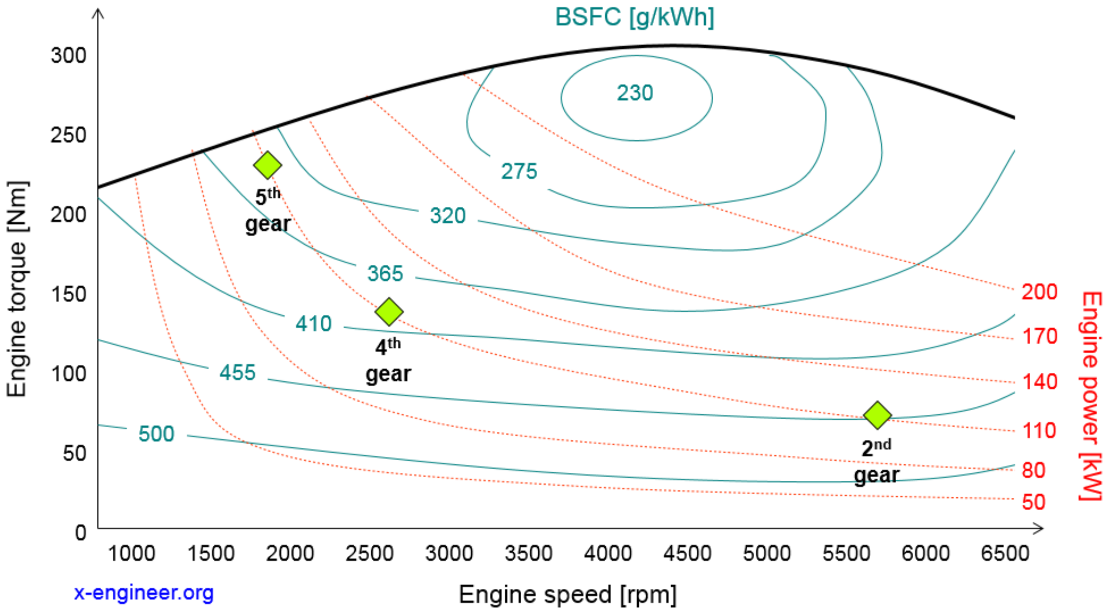
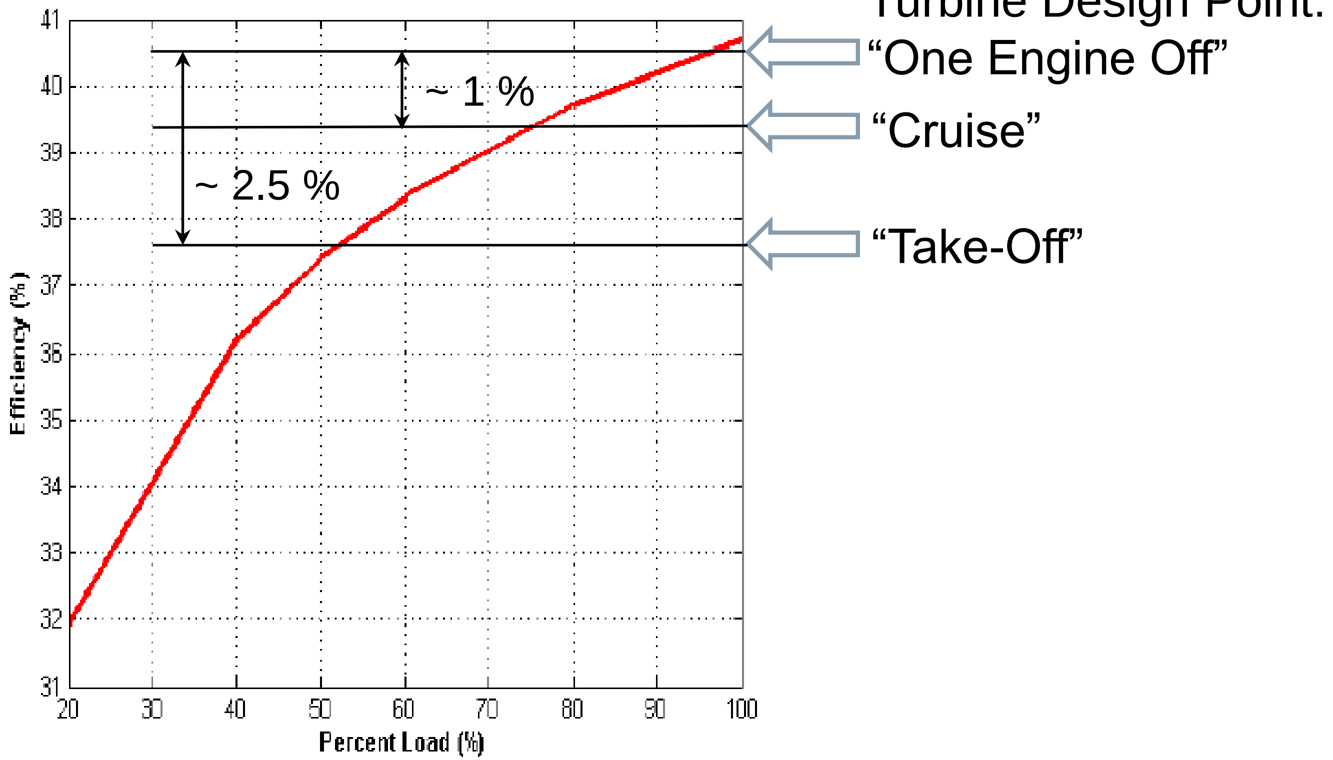
ICE for cars



Gas turbine for aircraft



*Images taken from **M. Ekwonu et al.:** „Modelling and Simulation of Gas Engines Using Aspen HYSYS" and x-engineer.com

Myth 3:
“Efficiency of gas turbines cannot be substantially improved”

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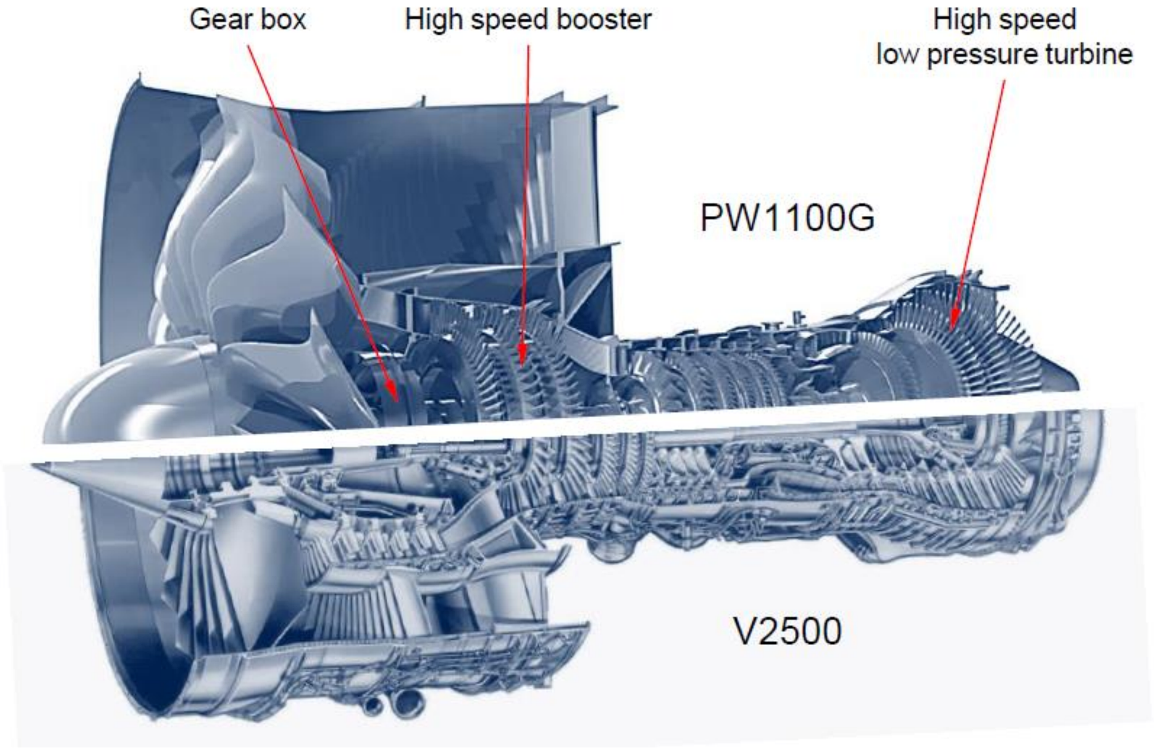

Comparison of Turbofan and Geared Turbofan

	V2533-A5	PW1133G-JM	
Stage count	1-4-10-2-5	1-G-3-8-2-3	reduced number of stages
Fan diameter	1613 mm 63,5 in	2057 mm 81 in	increased diameter
Bypass ratio	4,5	12	higher propulsive efficiency
Overall pressure ratio	33,4	46	higher thermal efficiency
Fuel burn	Basis	-16 %	reduced fuel burn
Noise emission	Basis	-20 EPNdB (accumulated)	reduced noise emission
NO_x emission	Basis	>-50 % (-50 % CAEP6)	reduced pollutant emission

”We took something so old and simple as a one-stage gear box and that resulted in a fuel burn reduction of 16 %.”

*Images taken from **J. Sieber:** „Aero Engine Roadmap 2050”

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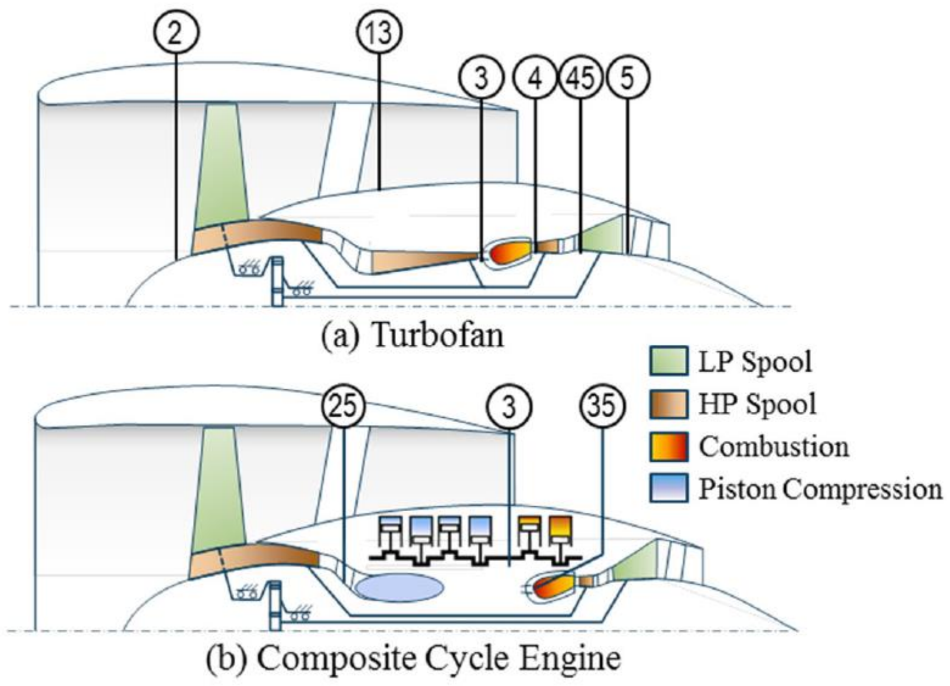


Parameter	Optimized GTF	CCE	CCE large	CCE IC
$TSFC_{ToC}$ [g/kN/s]	13.73	12.38	12.09	12.16
$TSFC_{CR}$ [g/kN/s]	12.62	11.51	11.23	11.45
$TSFC_{TO}$ [g/kN/s]	8.28	6.89	6.70	6.88
d_{Fan} [m]	2.840	2.867	2.867	2.867
m_{PPS} [kg]	5161.3	7283.2	7665.5	6009.5
ΔFB vs Y2050 GTF[%]	**-1.5**	**-9.6**	**-11.9**	**-12.5**
ΔFB vs Y2000 [%]	**-45.8**	**-50.3**	**-51.5**	**-51.9**

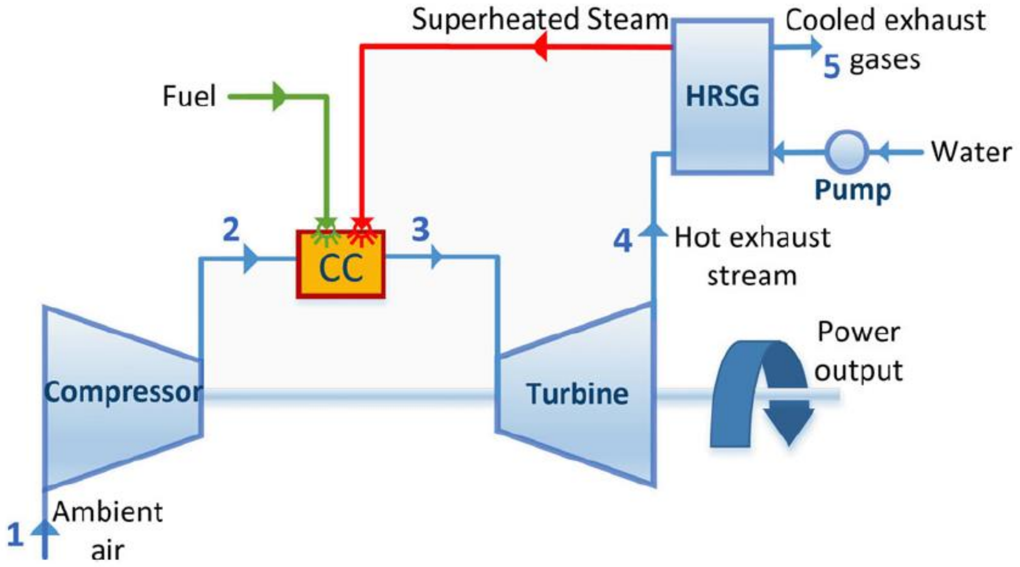
Improvements of 8 % to 10 % in fuel burn

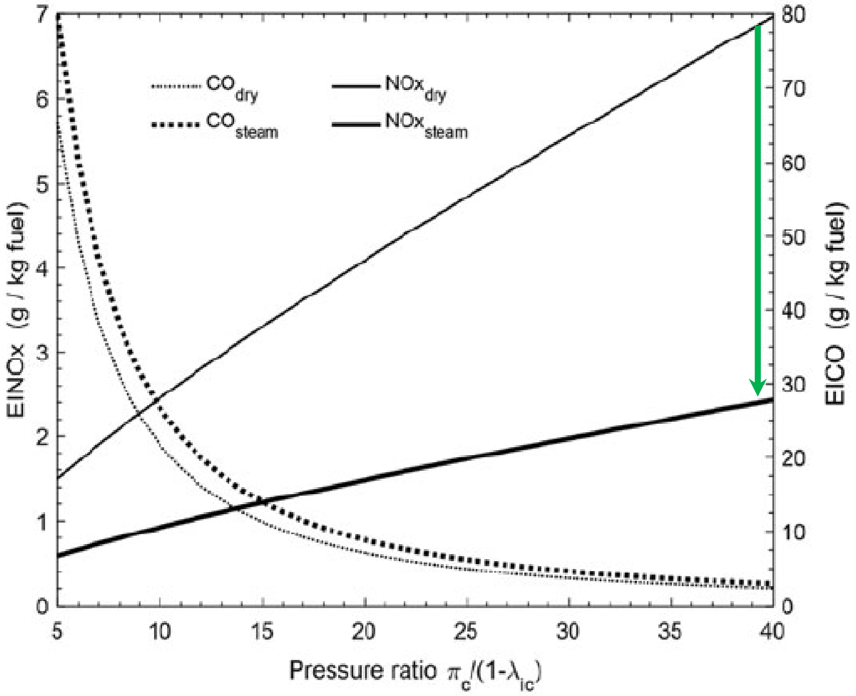
However:
CO2 and NOx emissions increase significantly

*Images taken from **S. Kaiser, M. Nickl:** „Investigations of the Synergy of Composite Cycle and Intercooled Recuperation”
Images taken from **S. Kaiser et al.: “A Composite Cycle Engine Concept for Year 2050”

Myth 3:
“Efficiency of gas turbines cannot be substantially improved”

60 % NOx reduction

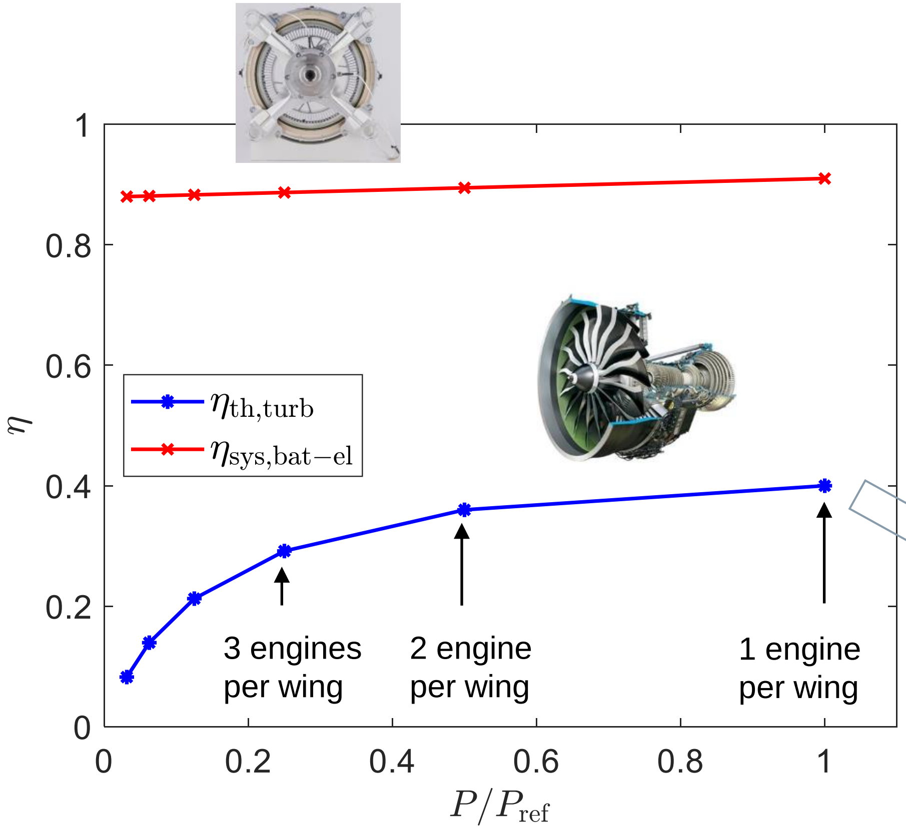




*Images taken from **H. Kayadelen:** „Thermoenvironomic evaluation of simple, intercooled, STIG, and ISTIG cycles”

Distributed electric propulsion:

Increasing $\frac{C_L}{C_D}$ by utilizing the scale behavior of electric motors



Wing distributed electrical propulsion

N propellers

$$\frac{C_L}{C_D} \sim 23$$

Conventional twin-engine

2 propellers

$$\frac{C_L}{C_D} \sim 16$$

*Images taken from **M. Hepperle** (2016)
** Data source: G. Atanasov (2018)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Aurora
FLIGHT SCIENCES
LILIUM
AIRSPACE X
EMBRAER
WORKHORSE
AIRBUS
XTI
AIRCRAFT
Bell Helicopter
A Textron Company
AIRBUS
VOLOCOPTER
CARTER
EHANG

A consequence of VTOLs:
New operation concepts

*Images taken Uber Elevate

Myth 4:
“Urban air mobility will solve urban congestion problems”

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Example: **Munich Metropolitan Area**
4.5 million inhabitants → 8.7 million trips/d

1% of trips with UAM: 87.0000 trips/d
10% of trips with UAM: 870.000 trips/d

Comparison:
MUC: 1.000 aircraft moves/d

*Following the Keynote of P. Plötner: „Future Perspectives of Aviation for Urban and Regional Mobility” (2019)

Myth 4:
“Urban air mobility will solve urban congestion problems”

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Capacity:
> 1000 landings/h (12 pads, 23 s/landing)
> 150 landings/h (4 pads, 96 s/landing)
> 24 landings/h per pad (60 s/landing)

Example: **Munich**
Operating hours (06:00 – 23:00)

1 % of trips with UAM:
> 61 large vertiports
> 126 medium vertiports
> 213 small vertiports

10 % of trips with UAM:
> 614 large vertiports
> 1365 medium vertiports
> 2132 small vertiports

*Following the Keynote of P. Plötner: „Future Perspectives of Aviation for Urban and Regional Mobility” (2019)

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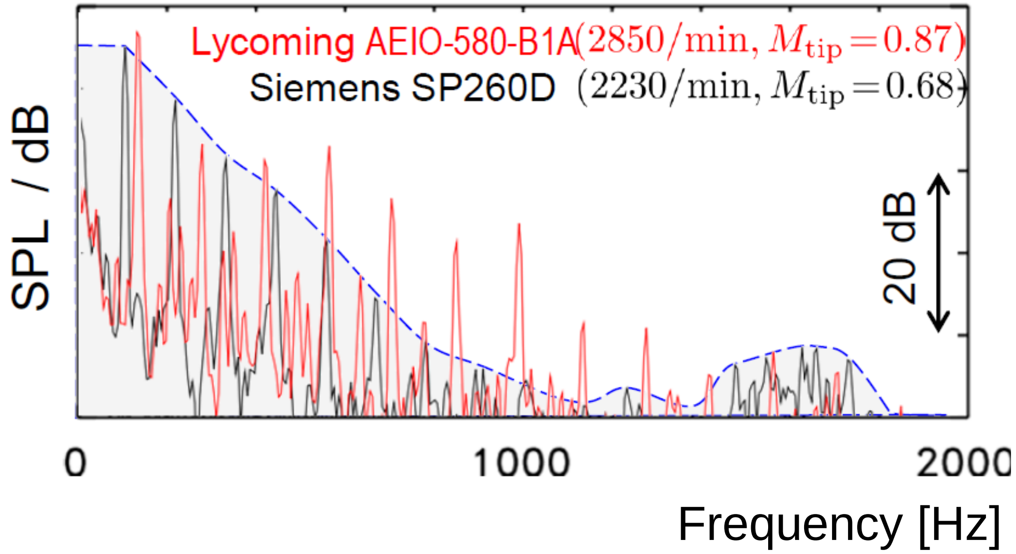
Public transport in Munich:
> 100 underground stations
> 150 suburban stations
> 173 tram stations
> 1006 bus stops

Share:
> 24 % in Munich City
> 11 % in Munich Suburbs

*Following the Keynote of P. Plötner: „Future Perspectives of Aviation for Urban and Regional Mobility" (2019)

Myth 5:
"Electric aircraft is silent"



- FFT analysis of EXTRA330 overflight reveals that the electric version has significantly lower noise emissions

- Probably due to less torque ripple than ICE

*Following the Keynote of J. Delfs: „E2Flight = silent ?" (2019)

Myth 5:
“Electric aircraft is silent”

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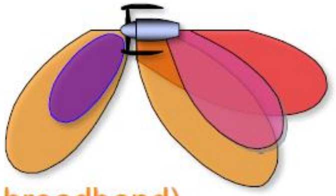
➤ **Take-off:**



engine noise

- jet
- fan tonal (+ broadband)
- (compressor)

➤ **Approach:**

engine noise

- jet
- fan broadband (+ tonal)
- (combustion + turbine)

airframe noise

- high lift devices
- landing gears
- parasitic sources

*Following the Keynote of J. Delfs: „E2Flight = silent ?” (2019)

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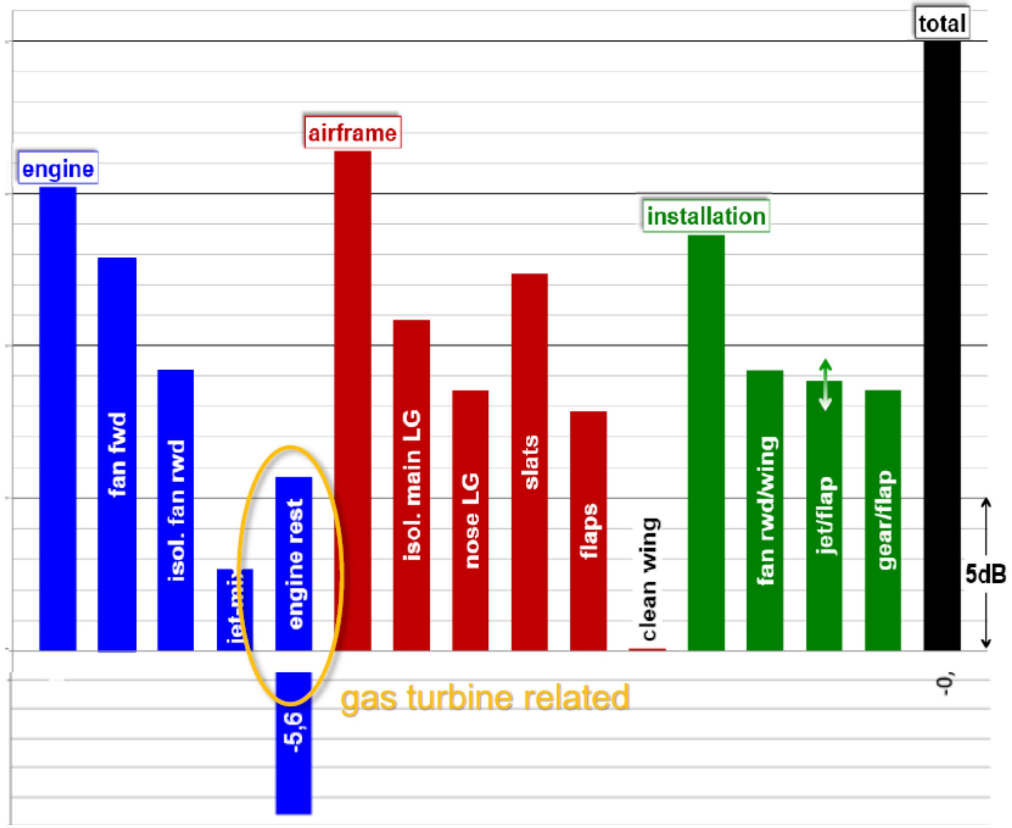

- Many additional noise sources beyond the propulsion unit
- Solely replacing the gas-turbine of a turbo-fan with an electric motor will not have a hearable effect since other noise sources prevail

*Following the Keynote of J. Delfs: „E2Flight = silent ?" (2019)

Myth 5:
“Electric aircraft is silent”

The aircraft design space that is available due to hybrid-electric propulsion could be used to build low noise emission aircraft

*Following the Keynote of J. Delfs: „E2Flight = silent ?” (2019)
*Image courtesy of NASA and Airbus Group

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A comparison of designs based on electric propulsion

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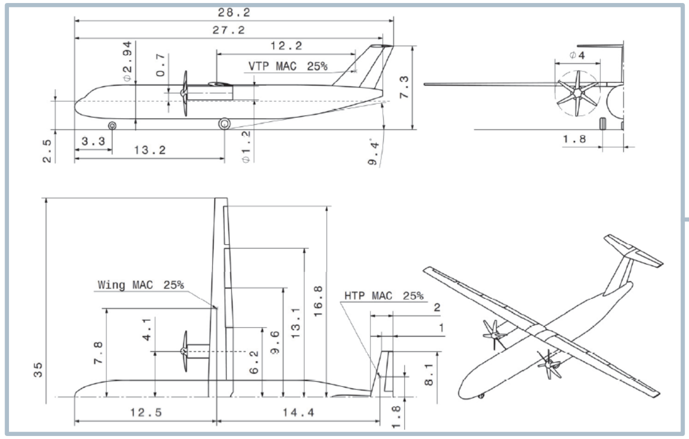
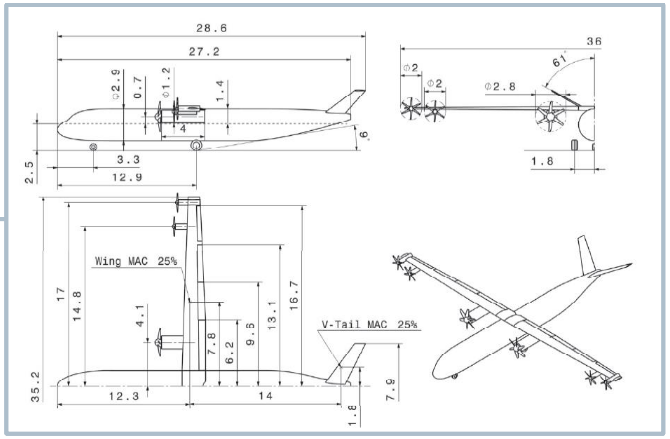
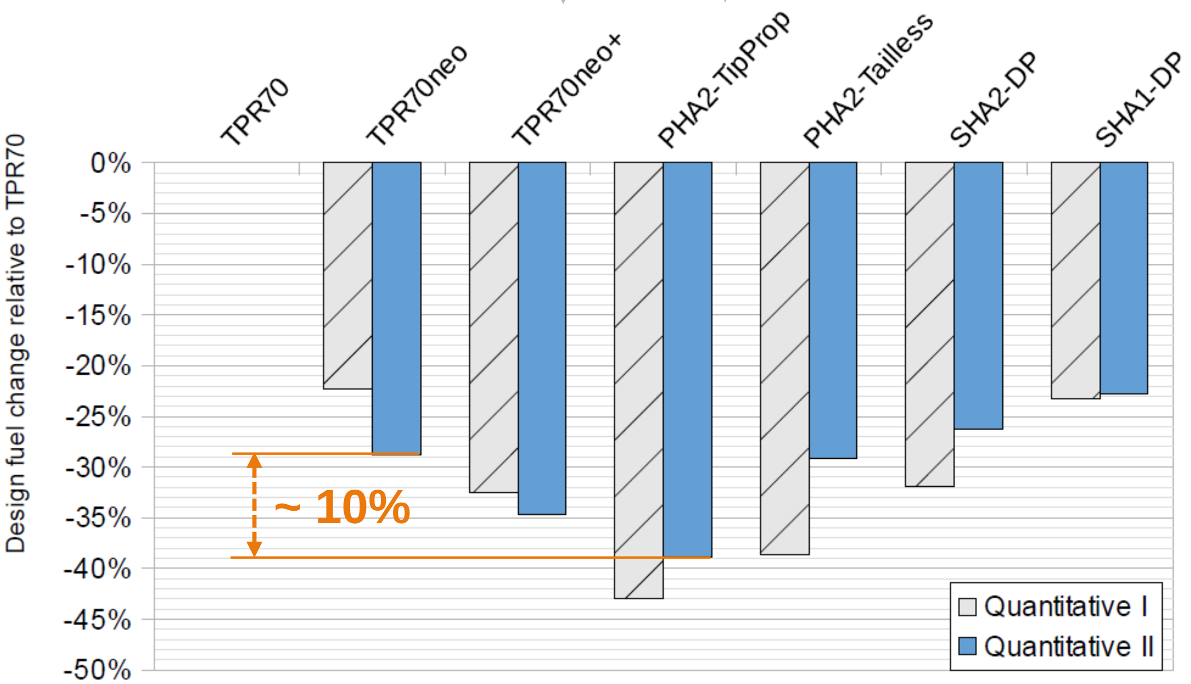




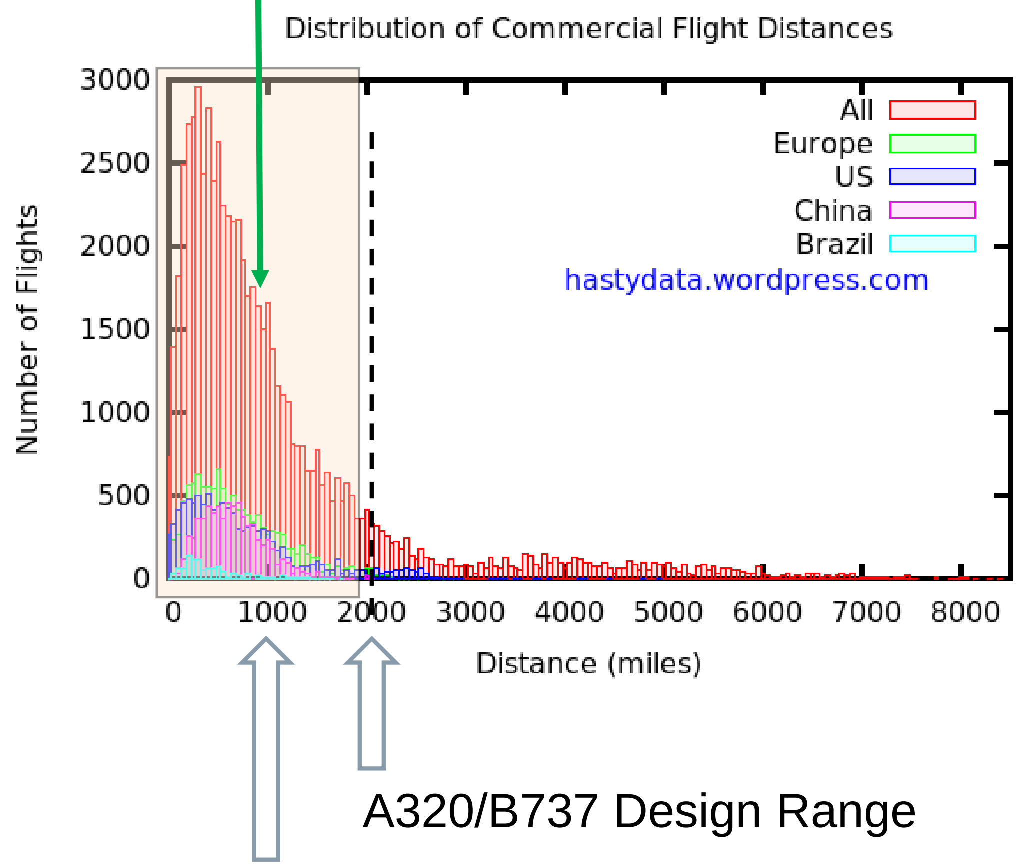


Mission distance: ~ 800 nm

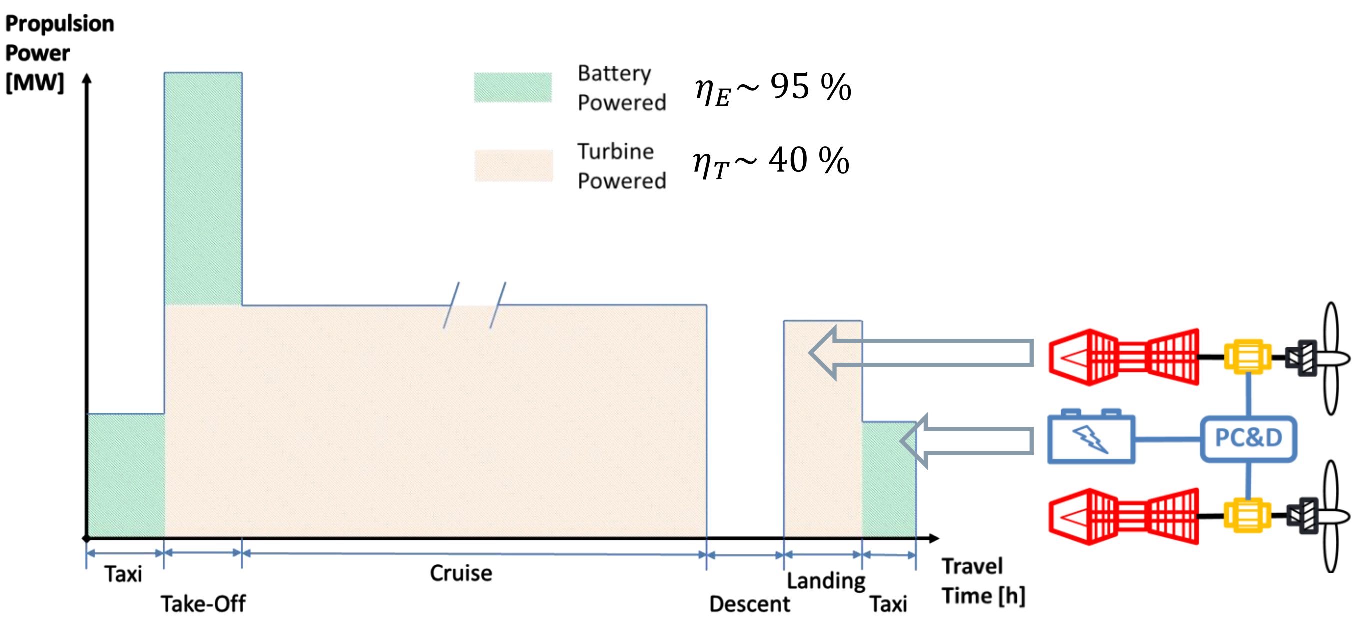
*Taken from M.Strack: „Conceptual Design Assessment of Advanced Hybrid Electric Turboprop Aircraft Configurations“ (2018)

Advantages of (hybrid) electric propulsion:
Mission Profile

Design Range of PHA2



Typical mission profile



*Plot taken from **hastydata.worldpress.com**
Data from: **https://openflights.org/data.html

Do we need superconductivity for that?

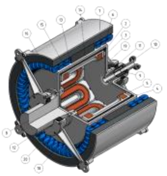
Breguet-Formula (Turbo-Electric):

$$R = \frac{v}{g \cdot SFC} \frac{C_L}{C_D} \ln\left(\frac{m_{fuel} + m_{empt}}{m_{empt}}\right)$$

Educated guess on power density
(incl. heat exchangers):

Component	Warm	Cold
Electric Machines	10 kW/kg	25 kW/kg
Power Electronics	30 kW/kg	60 kW/kg
Cables	40 kW/kg	100 kW/kg


SP2000D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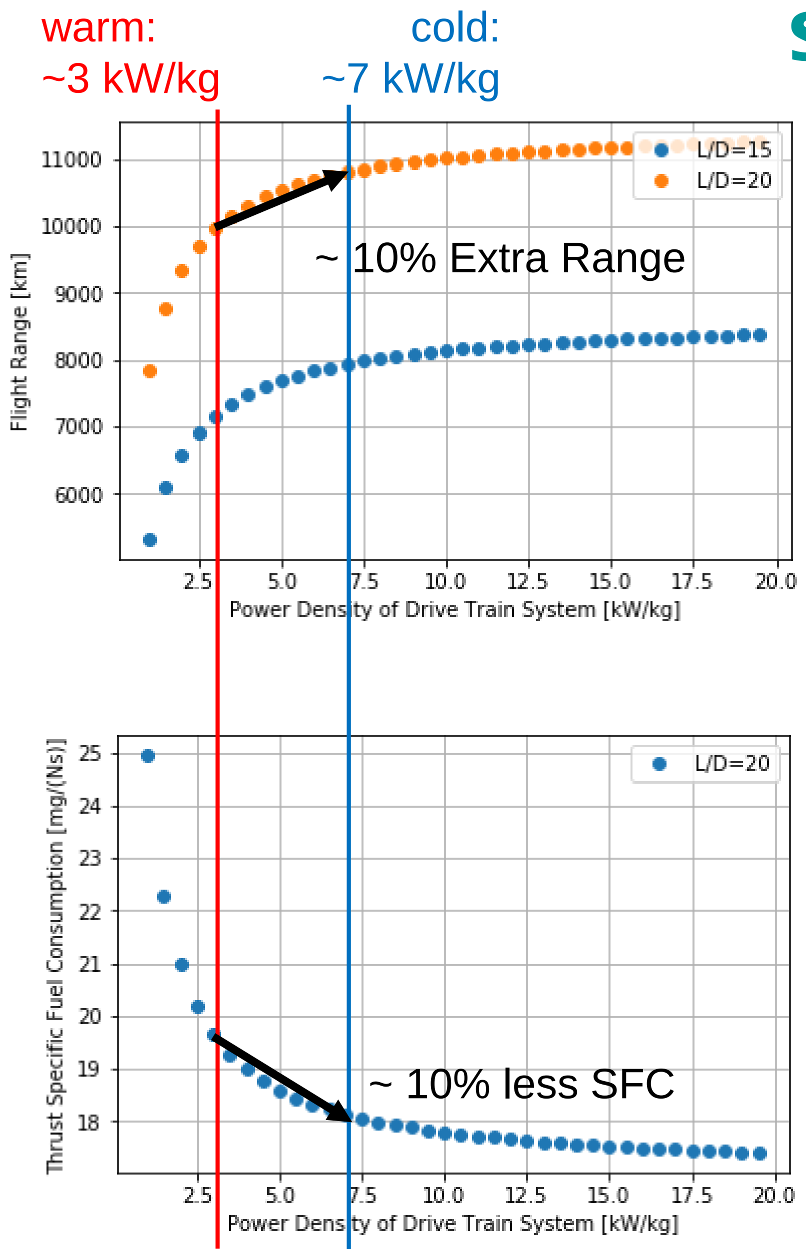

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Myth 6:
Superconductivity is an extraordinary complex technology

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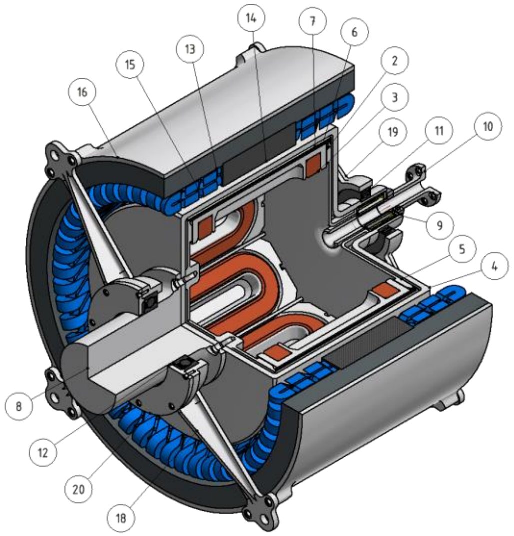
Siemens eAir
10 MW HTS Design

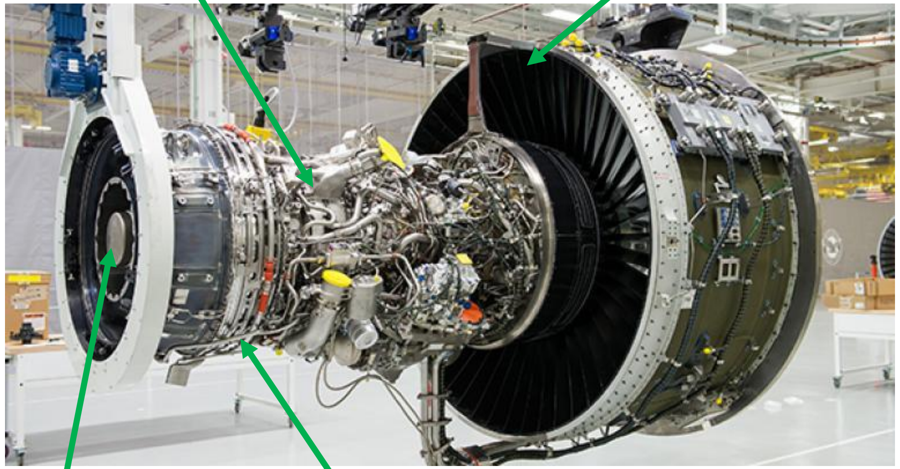


Brushless-DC Motor

Aircraft Turbo-Fan Propulsor

Combustion Chamber @ 1600 degC

Airgap
2 mm clearance on 2 m diameter



Multi shaft design

Complex fuel pipes and injection control

 *Image of a PW gas turbine engine, taken from:https://www.americanmachinist.com/news/pratt-whitney-machinists-union-settle-five-year-deal

Last Slides – Key Messages: We don't have to wait long

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We will have empirical evidence soon!

Last Slides

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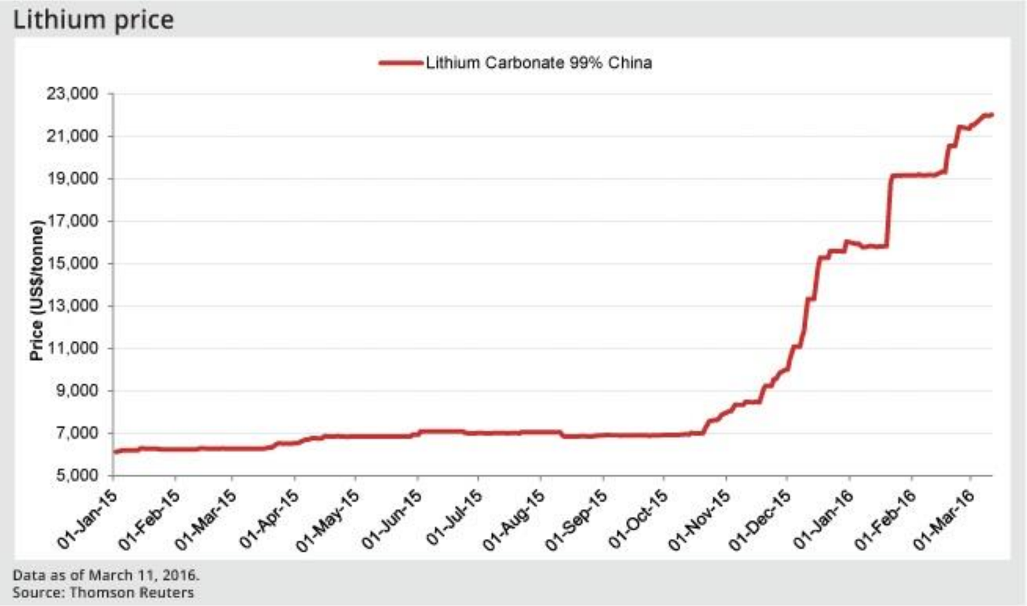
Rohstoff	2010	2011	2012	2013	2014	2015
Gold in US-Dollar pro Unze	1.225,46	1.569,52	1.666,54	1.410,8	1.266,34	1.160,59
Graphit in US-Dollar pro Tonne	1.514,58	2.511,46	2.487,5	1.400	1.325	1.175
Indium in US-Dollar pro Kilogramm	567,26	735,31	625	613,33	718,2	412,33
Kadmium in US-Dollar pro Kilogramm	4,09	2,95	1,92	2,02	1,8	1,1
Kobalt in US-Dollar pro Kilogramm	45,33	38,6	30,75	29,01	31,81	29,11
Kupfer in US-Dollar pro Tonne	7.534,18	8.820,53	7.949,44	7.332,19	6.859,2	5.501,12
Lithium-Minerale in US-Dollar pro short t*	676,94	745	821,22	821,22	6.526,59	6.375,03
Magnesit in Euro pro Tonne	70	91,83	90,54	70	70	71,67
Magnesium (Magnesium) in US-Dollar pro Tonne	2.920	3.127,7	3.134,72	2.726,04	2.481,14	2.146,91
Mangan in US-Dollar pro Tonne	2.549,17	3.316,46	2.786,67	2.319,71	2.225,42	1.818,75



Invest in Lithium, because the future of flight is electric!

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