Minimalistic Use of Hybrid-Electric Technologies for Aircraft Performance Improvement in Off-Design Operation

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Outlines

- Background and motivation.
- Reference aircraft.
- Conceptual sizing of state-of-the-art technology level hybrid propulsion chain for off-design optimization.
- Finding synergies.
- Results at aircraft level.
- Asessment at global fleet level.
- Assessment based on US-market air transport data.
- Conclusions and outlook.

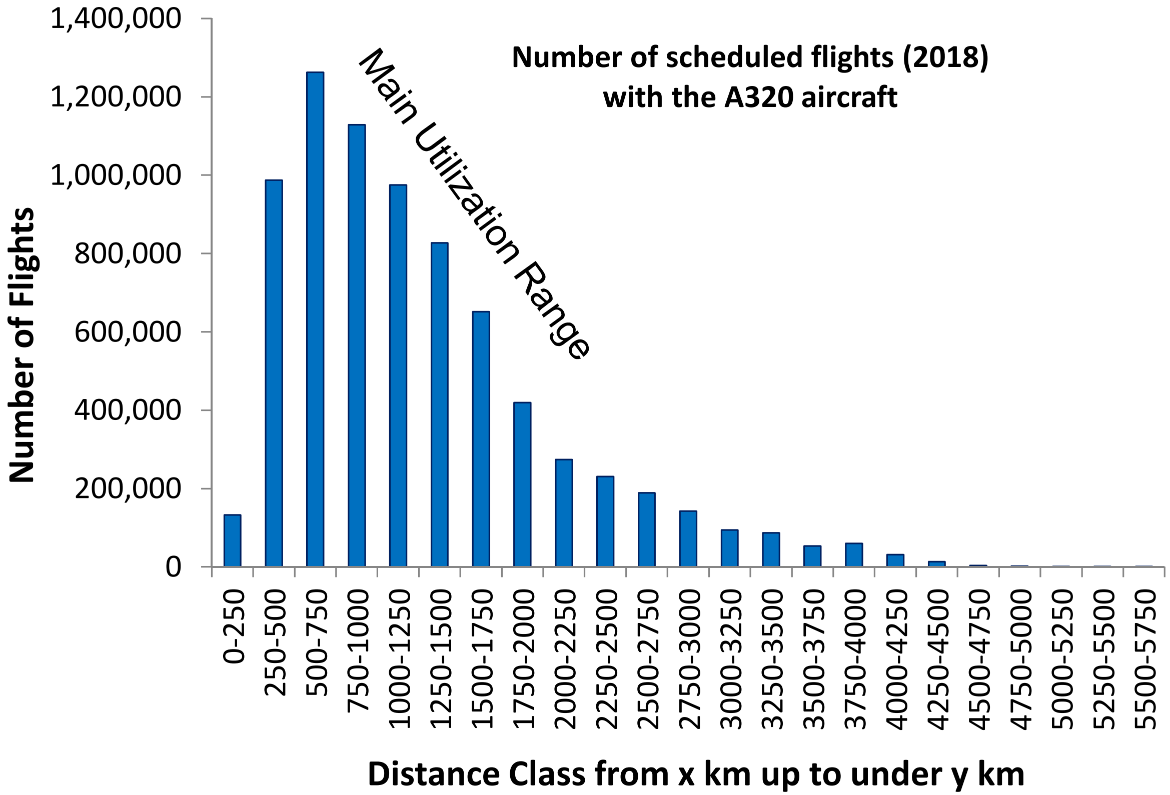
Motivation and Background

A320 – the most frequently flown aircraft in the world:

- ~14% of global flights
- ~70% of flights up to 1500km (800nm)

Off design operation (taxi & descent):

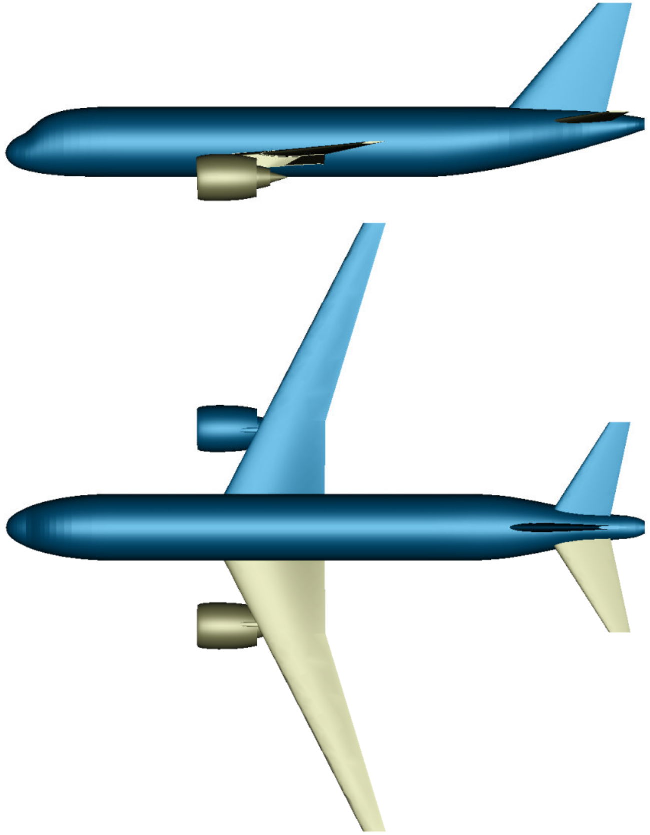
- Greatest performance penalty at short missions
- Frequency of operation proportional to emmisions around airports



Off-design optimization potential:

- lower emissions around airports
- less overall fuel burn

Reference Aircraft: Conceptual-Level Model Calibrated on A320neo



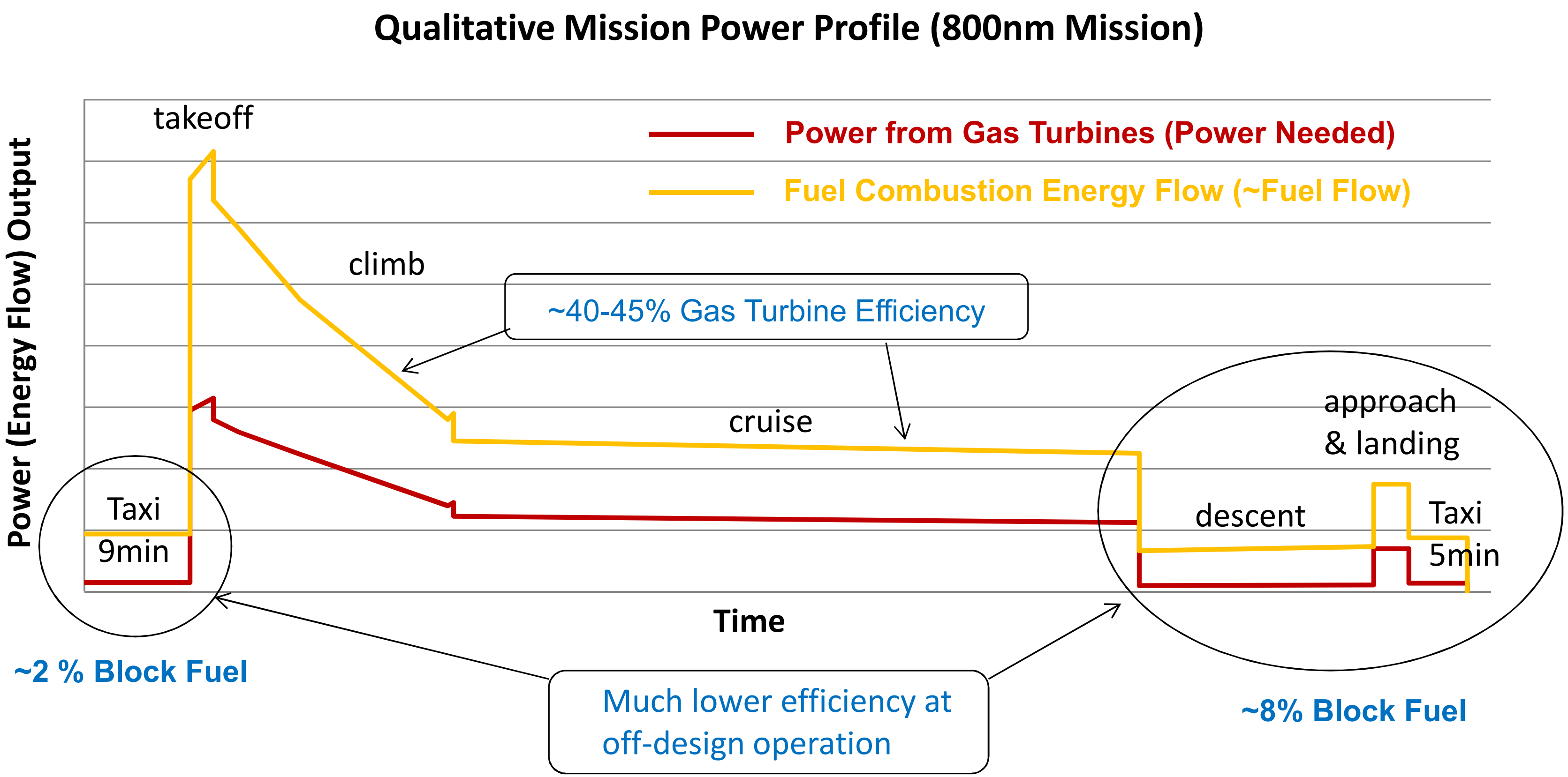
Study assumption: All-Electric Systems (no bleed air)

TLARs	
Design Range	3100 nm
Design Mach Number	0.78
Initial Cruise Altitude	33000 ft
TOFL	2200 m
Approach Speed	132 KCAS
Max Payload	20 t
Design Payload	17 t

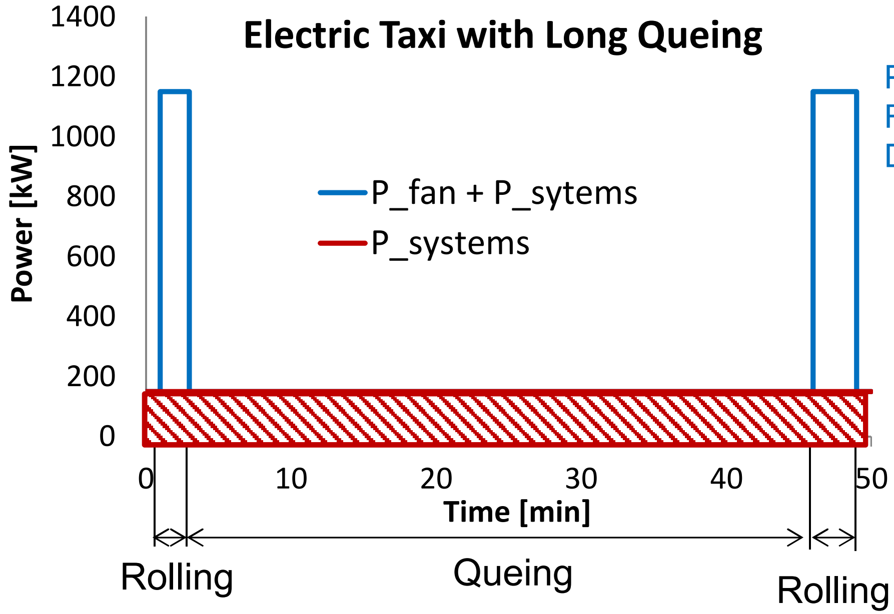
Top-level A/C Parameters	
MTOM	79 t
OEM	44.3 t
Design Mission Fuel	17.8 t
AC T/O Static Thrust	240 kN

DLR

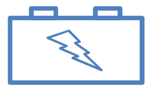
Off-Design Fuel Burn



Sizing Requirements for the Hybrid Chain



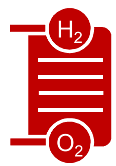
Power Requirement Dominant



High-Power-Density Battery (e.g. LiPo technology)

- Low Energy Density
+ Fast charge / discharge
  → Recharged during flight

Energy Requirement Dominant



High-Temp. Fuel Cells

e.g. SOFC Technology & Kerosene Reformer

- Low Power Density
+ Not sized by energy
+ ~70% tot. energy efficiency

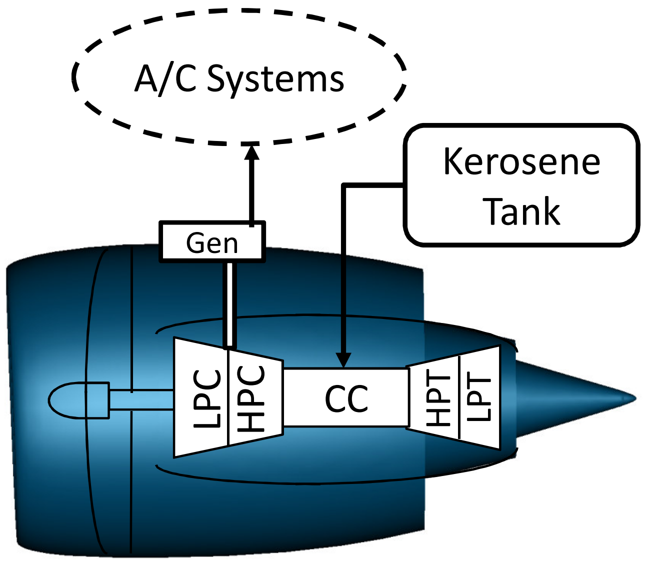
Potential

Phase	Ref. Aircraft Taxi Fuel [kg]	Hybrid Taxi Fuel [kg]
9 min Taxi	86	12*
60 min Taxi	576	27*

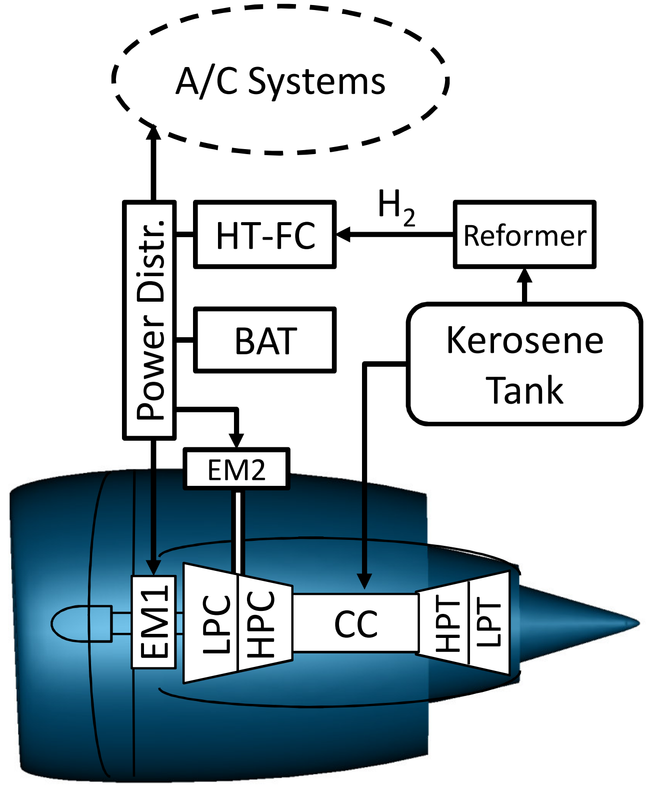
*fuel for battery recharging included

Highly efficient taxi, regardless of taxi time without oversizing the electric components

Setup of the Hybrid Chain for Efficient Off-Design Operation



Bleedless



Bleedless

Sizing of Hybrid Components

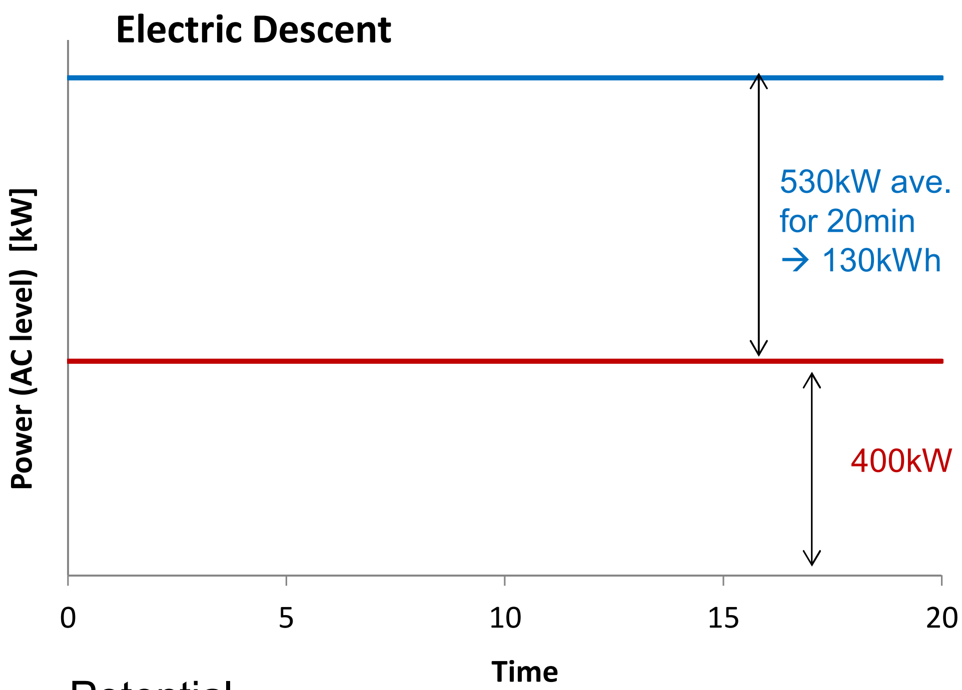
State-of-the-Art Technology
Prototype Level Assumed

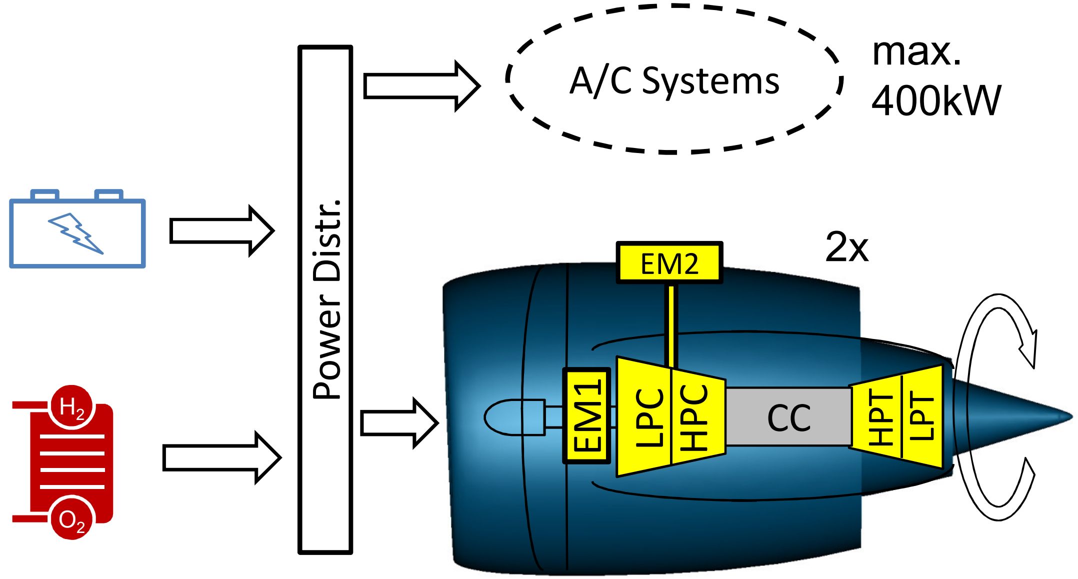
Hybrid Chain Components	Req. Power [kW]	Req. Energy [kWh]	Eff. [%]	sp.P [kW/kg]	sp.E [Wh/kg]	Install. Factor* [-]	Total Mass [kg]	
E-Motors	1500	-	95%	5.9	-	1.1	280	Sized for eTaxi
Inverters	1583	-	98%	113	-	1.1	15	
Cooling (eMot + Contr)	107	-	-	1.0	-	1.1	120	
Battery Packs	1620	160	-	2.6	130	1.1	1340	
FC (SOFC) System	400	-	70%	0.3	-	1.1	1465	Sized for complete offtakes
Total	**-**	**-**	**-**	**-**	**-**	**-**	**3220**	

*includes power distribution system and structural integration

DLR

Sizing Requirements for the Hybrid Chain





Potential

Phase	Ref. Aircraft Descent Fuel [kg]	Hybrid Descent Fuel [kg]
Descent (20 min)	170	35*

*fuel for battery recharging included

Target: same Engine RPM as in normal idle

➔ Idle OPR-level to enable rapid engine restart

Challenges:
- Sufficient power / energy
- Turbine thermal issues

Detailed engine & descent profile analysis needed

Aircraft Component Synergies

4% Smaller gas turbine

- No offtakes
- Boosted by e-motor during takeoff

Remove APU & Generators

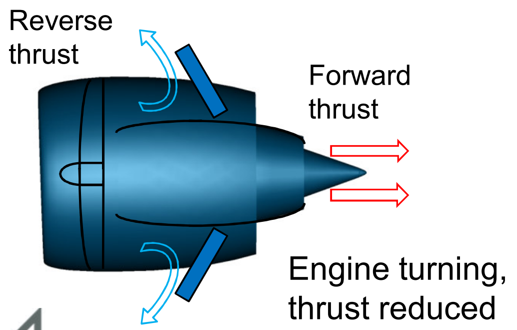
- Replaced by battery and fuel cell

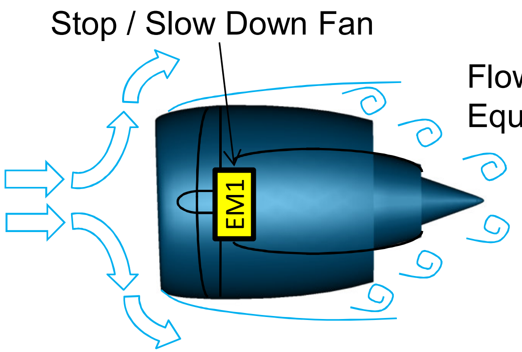
Remove thrust reverser:

- Fan slowed down / stopped during landing with e-motors.

Potential

Aircraft Component	Rel. Mass Change [-]	Total Mass Change [kg]
Gas Turbines	-4%	-160 kg
APU & Generators	-100%	-430 kg
Thrust Reversers	-100%	-1030 kg
Total	**-**	**-1620kg**





Required Analysis:

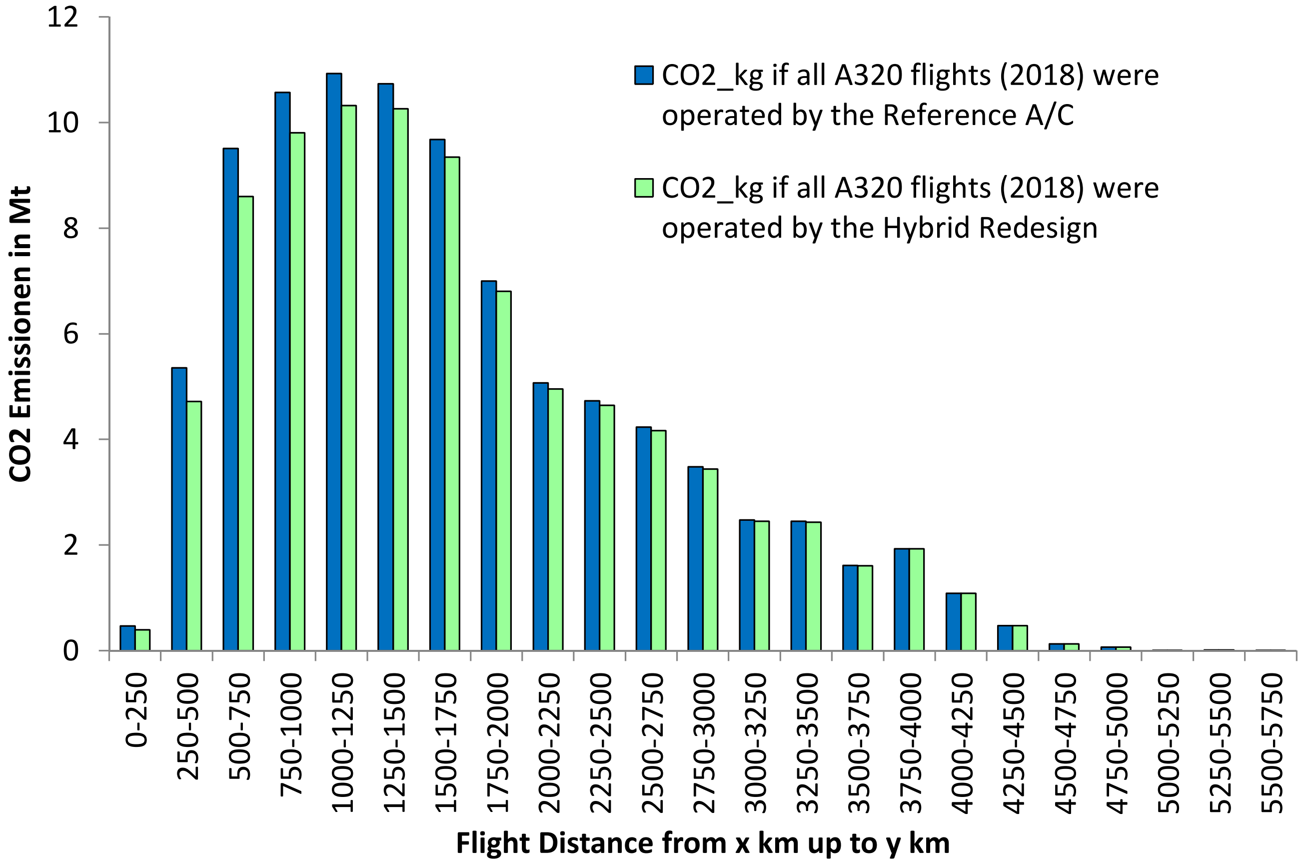
- Slow down or stop fan
- Effects of fan structure
- E-motor torque needed

Hybrid Aircraft Compared with the Reference

Parameter	Ref. A/C	Hybrid A/C	Rel. Delta	
MTOM	79.0 t	82.2 t	+4.0%	deltaOEM due to hybrid = +3.2t deltaOEM synergies = -1.6t Resizing includes snowball factors
OEM	44.3 t	47.3 t	+6.8%	
MLM	67.4t	70.5 t	+4.6%	
Design Mission Payload	17.0 t	17.0 t	+0.0%	Same payload capabilities
Design Mission Fuel (3100nm)	17.8 t	17.9 t	+0.5%	Similar design mission performance
AC T/O Static Thrust (ISA, SL)	241 kN	249 kN	+3.3%	Same approach speed and takeoff dist.
Wing Ref Area	124.4 m^2	130.0 m^2	+4.6%	
Wing Span	35.8 m	35.8 m	+0.0%	Gate limit 36 m
L/D in cruise	17.80	17.75	-0.3%	Lower L/D due to smaller aspect ratio
TSFC (mid cruise)	0.053 kg/h/N	0.0525 kg/h/N	-1.6%	Due to 4% offtakes with 70% eff. (HT-FC)
Design Mission Block Fuel	15150 kg	15285 kg	+0.9%	Similar design mission performance
800nm Mission Block Fuel	4375 kg	4120 kg	-4.0%	Improved average performance
Off-Design Fuel*	410 kg	165 kg	-60%	Highly efficient off-design

*Assumed: 9min taxi-out, 5min taxi-in, 30 sec. engine spool-up and neligible cool-down time

Potential Global Effect on Emissions



-4.7% Global CO_2 emission reduction potential, based on global A320 flight data in 2018.

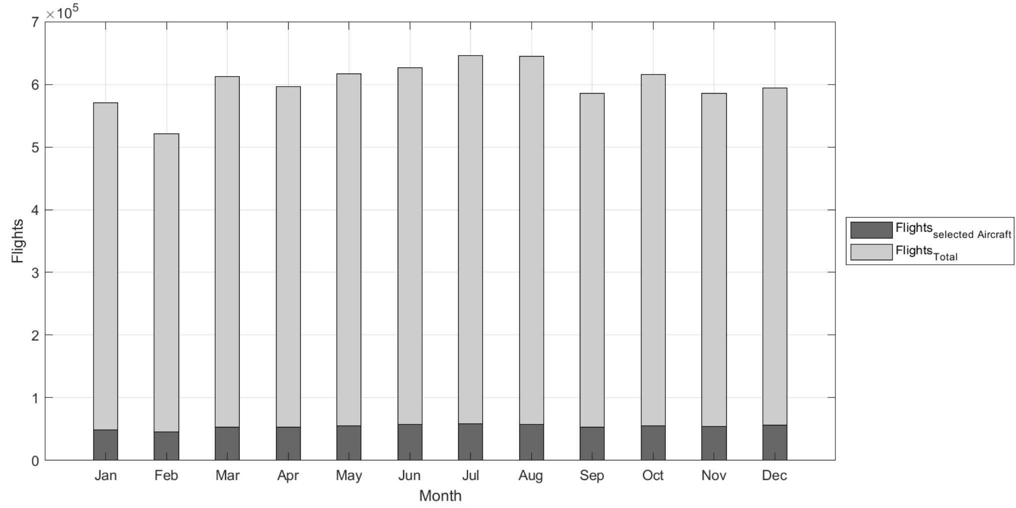
Simplifications / Assumptions:

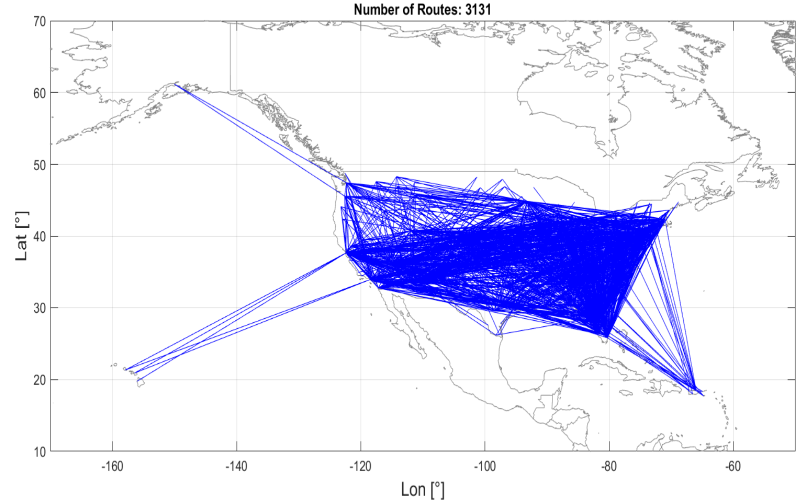
- Standard passenger payload for all flights
- 9min taxi-out & 5min taxi-in
- 30 sec spool-up and negligible cool-down time for engine.

Furthemore: NOx-less taxi
~12% NOx emission reduction in LTO Cycle.

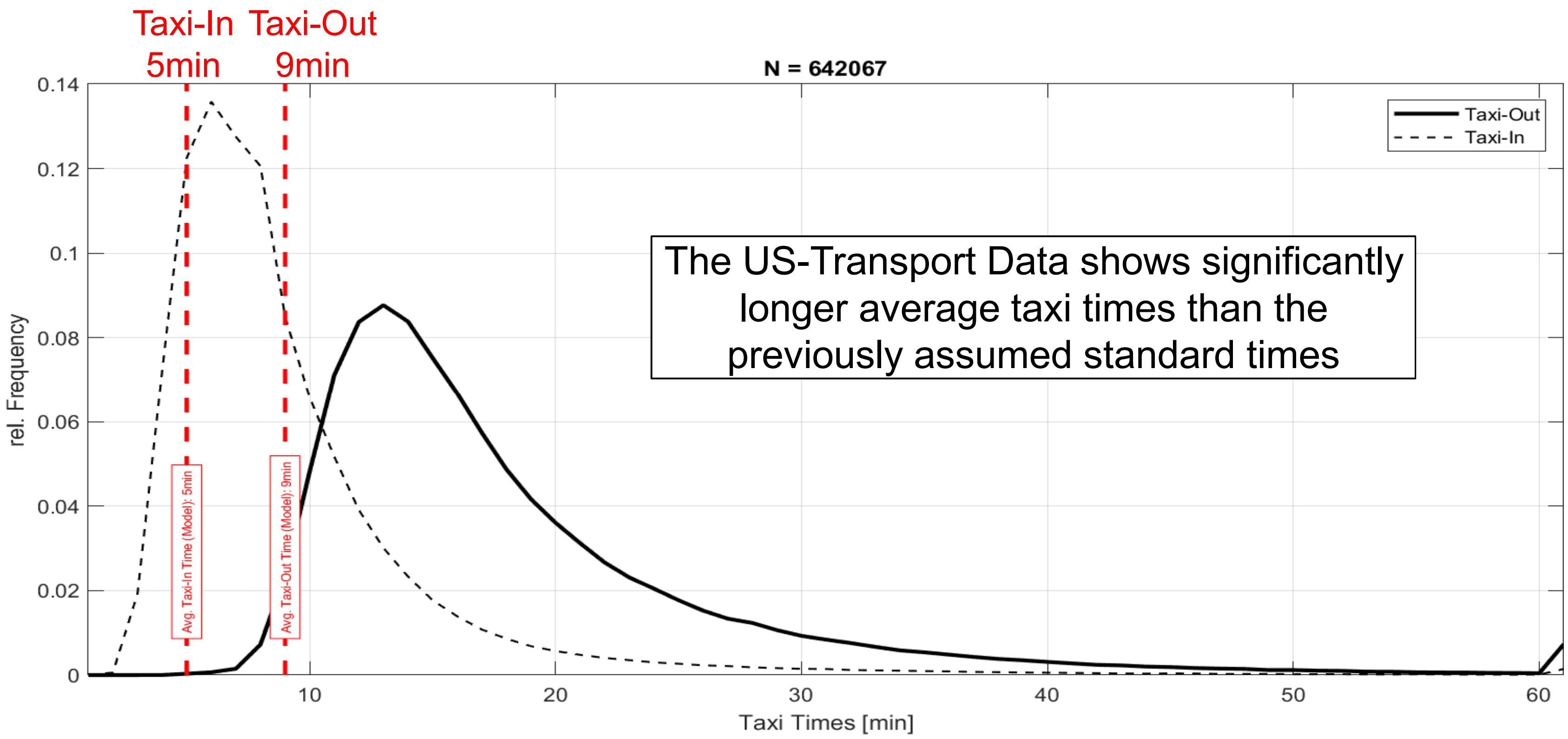
Analysis Based on US-Market Data (2018)

- Analysis based on published data by the Bureau of Transportation Statistics (BTS) form 2018.
- The data contains taxi time information (Taxi-In & Taxi-Out), flight distance, Registration, etc.
- For the analysis, all flights of the aircraft A320/A320neo were used:
  - 9 airlines
  - 551 registered aircraft
  - Approx. 650.000 flights
  - 3131 Routes



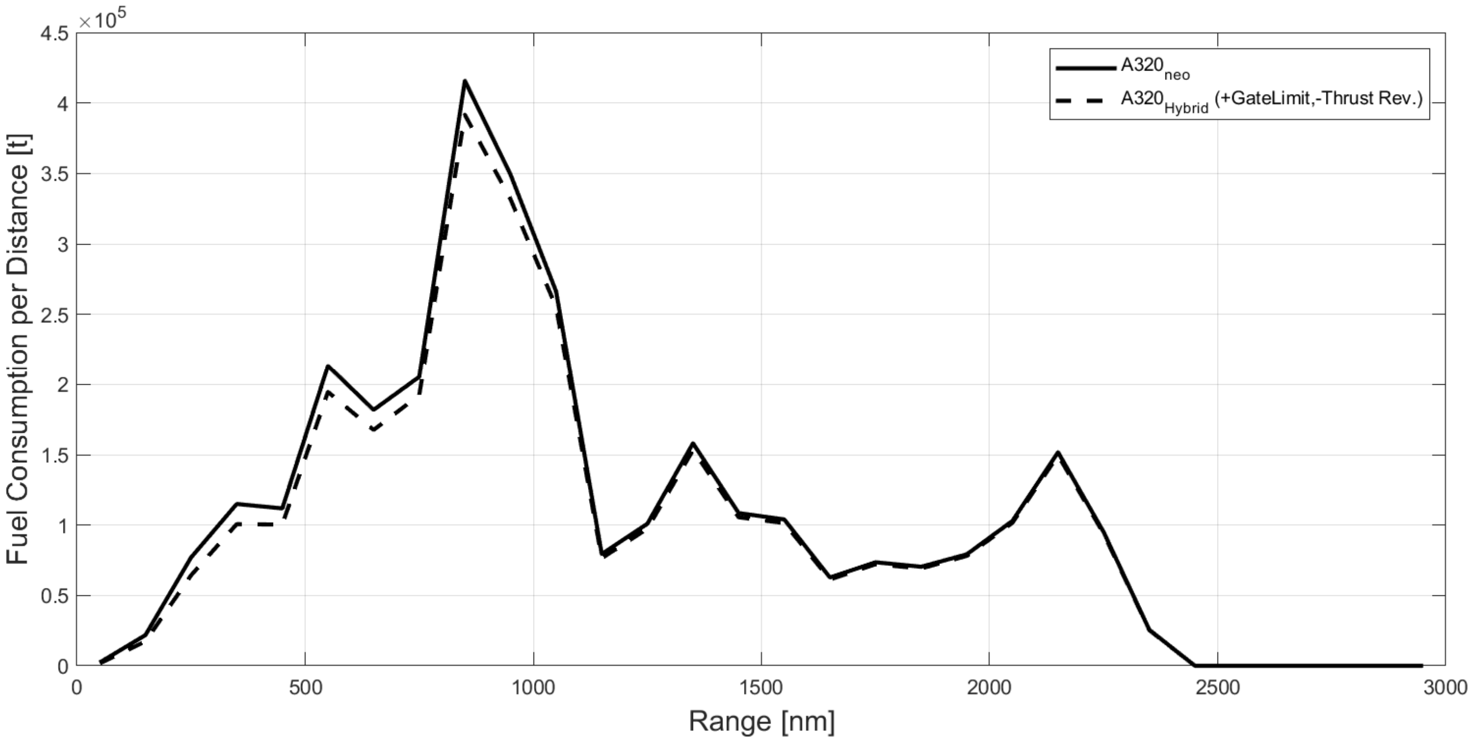


Analysis on the US-Market with Actual Taxi-Time Data



Potential NOx reduction in LTO ~ 20%

Analysis on the US-Market with Actual Taxi-Time Data



Fleet-level CO2 reduction potential ~ 5.1%

Conclusions and Outlook

Conclusions:

- State-of-the-art electric propulsion technology is potentially sufficient to allow ~5% CO_2 emissions reduction at fleet-level of A320neo-like aircraft with an off-design operation optimization approach.
- 10%-20% reduction potential of NOx emissions around airports.
- A more detailed research on the assumed techno-bricks is needed to consolidate the numbers.

Outlook:

- With the advancement of electric propulsion technologies, the savings potential increases.
- This approach is synegetic with hydrogen-storage studies, where the fuel cell would not need a reformer and various fuel cell types can be considered.
- The overall fuel benefit is increasingly important for renewable energy storage, e.g. hydrogen or power-to-liquid, as fuel costs play a more crucial role.

Thank you for your attention!

Off-Design Optimization Principle