



Hybrid Electric Turbofans from an Engine Performance Perspective Frowin Winkes

Frowin Winkes

- Grew up next to the Dalahäst “factory”
- Masters in Applied Mechanics at Chalmers
- Master thesis on *Off-design Performance Modelling of a Propfan Aero Engine – 2023*
- *Research Engineer in dept. Future Concepts at GKN Trollhättan*



GKN Aerospace in Numbers



£3.5bn
SALES in 2024



32
MANUFACTURING
LOCATIONS



16,000
PEOPLE



4 GLOBAL
TECHNOLOGY
CENTRES



12
COUNTRIES

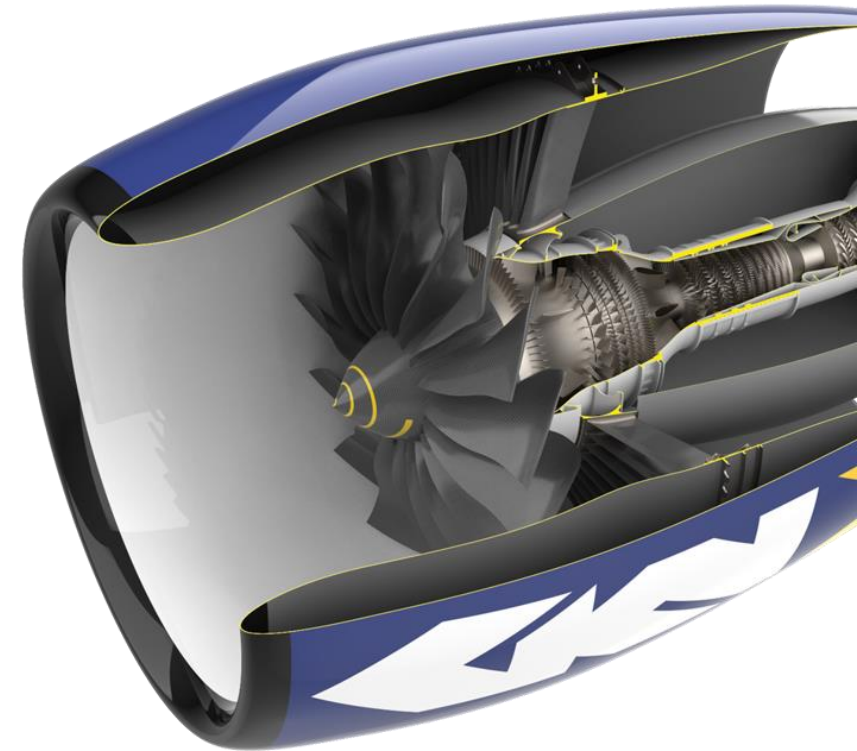
ON BOARD 

100,000
FLIGHTS A DAY



Background

- **Air transport keeps growing post covid**
- **High demand for reducing emissions and finding sustainable alternatives to our current technologies**
 - Novel engine architectures are of interest again
- **Some form of revolutionary technology is required to meet Paris agreement goals**



Why Electric Hybridisation?

- **Future aircraft are expected to consume more electric power**
 - Electric climate control
 - Electric actuators (flaps, elevators, ailerons, etc.)
 - Passenger comforts (USB-chargers, entertainment, etc.)
- Larger generators are likely required on the next generation of engines. Can we get the engine to benefit instead?
- **Electric machines offer a method for optimising the turbofan efficiency to each flight segment.**



What makes a turbofan efficient?

Propulsive Efficiency

Thermal Efficiency

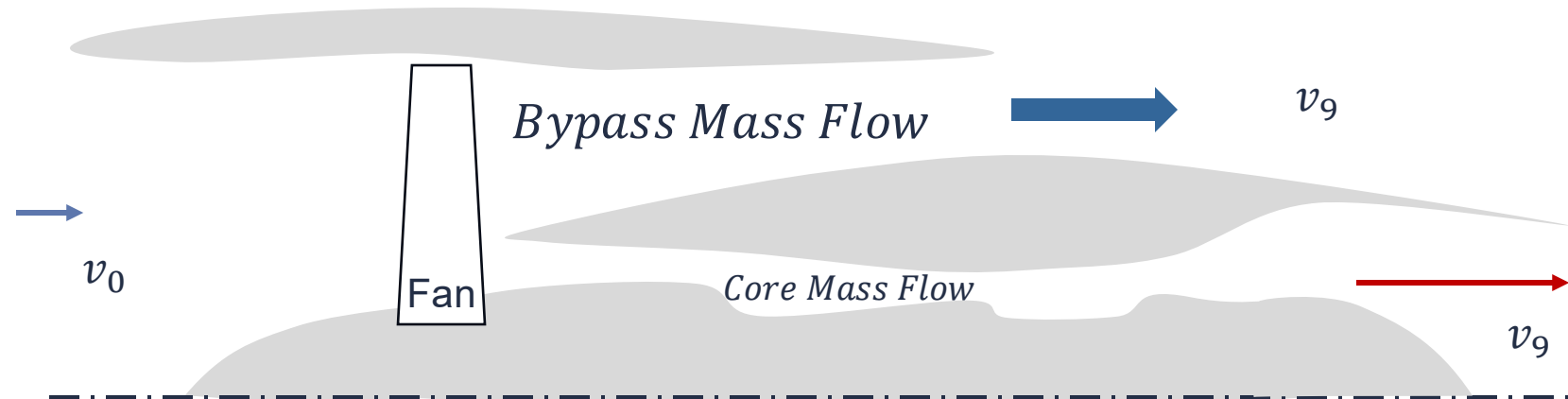
Propulsive Efficiency

Propulsive Efficiency

- Bypass : Large mass flow of relatively slow and cold air
- Core : Small mass flow of fast and hot gases

$$\eta_p = \frac{2}{1 + \frac{v_9}{v_0}}$$

$$BPR = \frac{\text{Bypass Mass Flow}}{\text{Core Mass Flow}}$$



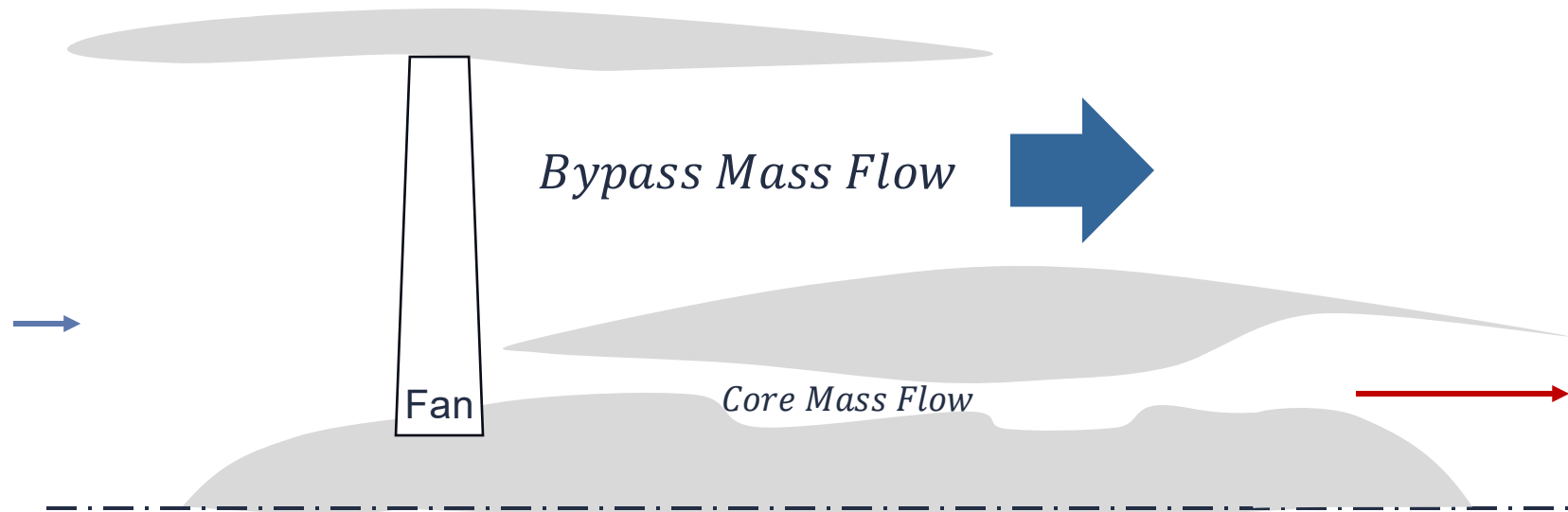
Propulsive Efficiency

Propulsive Efficiency

- Bypass : Large mass flow of relatively slow and cold air
- Core : Small mass flow of fast and hot gases
- Slow air is efficient

$$\eta_p = \frac{2}{1 + \frac{v_9}{v_0}}$$

$$BPR = \frac{\text{Bypass Mass Flow}}{\text{Core Mass Flow}}$$



What is stopping us?

- **Ground clearance during landing**
 - Taller landing gear is heavy
- **Larger nacelles are heavy and increase drag**



What makes a turbofan efficient?

Propulsive Efficiency

Propulsive efficiency increases with bypass ratio, ergo we want to maximise BPR!

But...
Increasing BPR can increase weight and drag

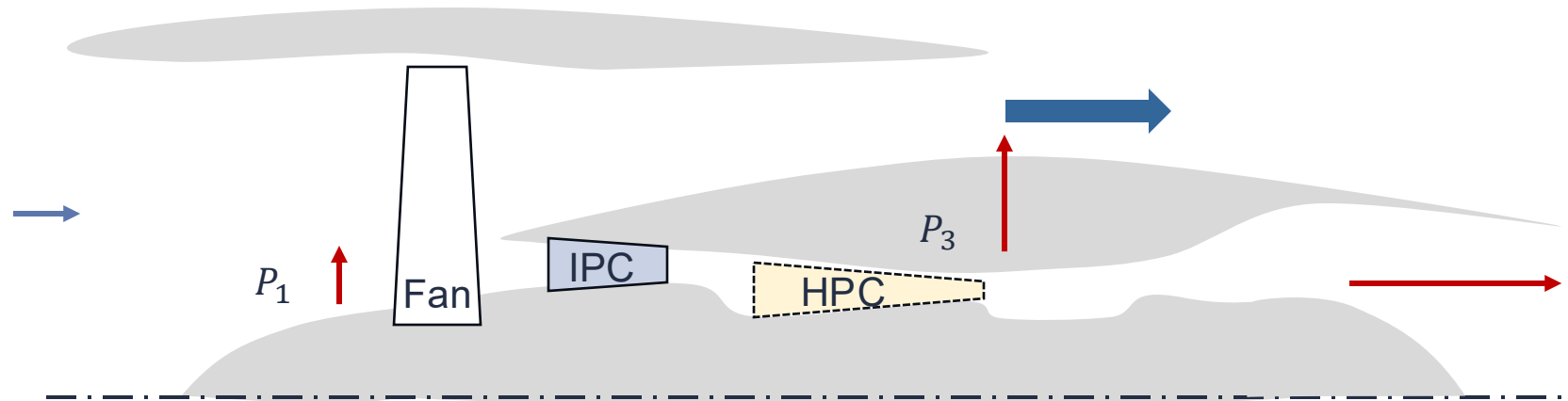
Thermal Efficiency

Thermal Efficiency

Thermal Efficiency

$$\eta = 1 - \left(\frac{1}{OPR^{\frac{\gamma-1}{\gamma}}} \right)$$

$$OPR = \frac{P_3}{P_1}$$



Thermal Efficiency

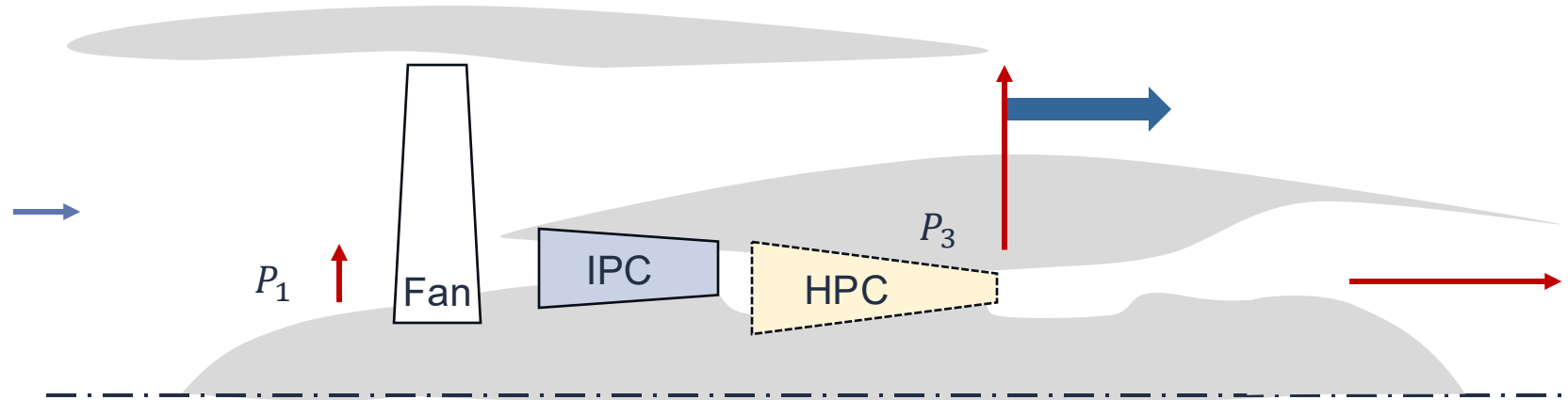
Thermal Efficiency

- Increasing OPR leads to higher theoretical thermal efficiency

$$\eta = 1 - \left(\frac{1}{OPR^{\frac{\gamma-1}{\gamma}}} \right)$$

$$OPR = \frac{P_3}{P_1}$$

$$\lim_{OPR \rightarrow \infty} \eta(OPR) \rightarrow 1 = 100\%$$



What is stopping us?

- **Higher OPR requires more compressor stages**
 - Heavy
 - Increased Complexity
 - Minimum blade height
- **Higher OPR leads to higher temperatures in the engine due to compression losses**
 - Requires hi-tech materials, coatings, etc.
 - Higher wear on engine parts



Thermal flame coating surface treatment at Trollhättan site

What makes a turbofan efficient?

Propulsive Efficiency

Propulsive efficiency increases with bypass ratio, ergo we want to maximise BPR!

But...
Increasing BPR can however increase weight and drag

Thermal Efficiency

Thermal efficiency increases with overall pressure ratio

But...
Compressor stages are heavy, and high OPR leads to higher temperatures

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But...
Compressor stages are heavy and high OPR leads to higher temperatures

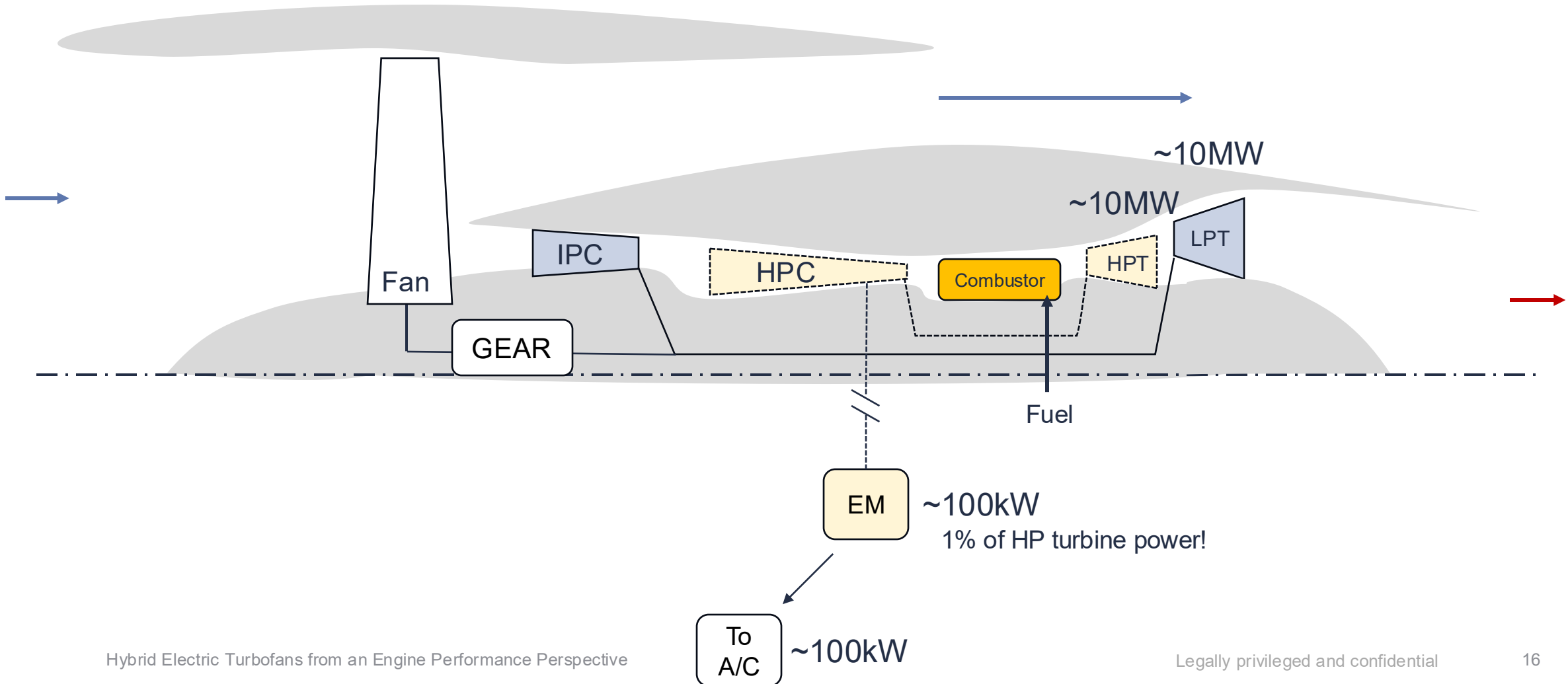
Efficient engines lead to low specific fuel consumption (SFC)

$$\rightarrow \frac{g}{kN s}$$

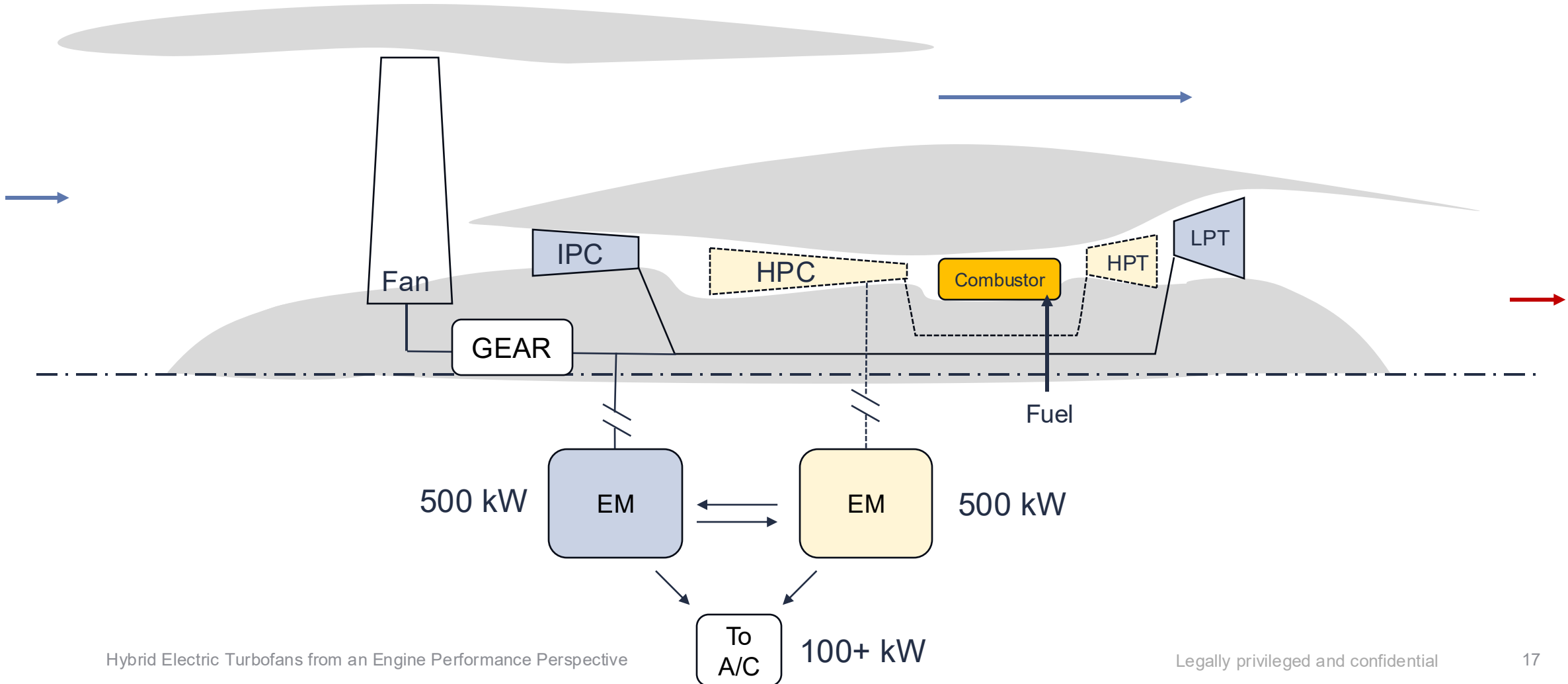
Weight leads to more total fuel consumption

$$\rightarrow kg$$

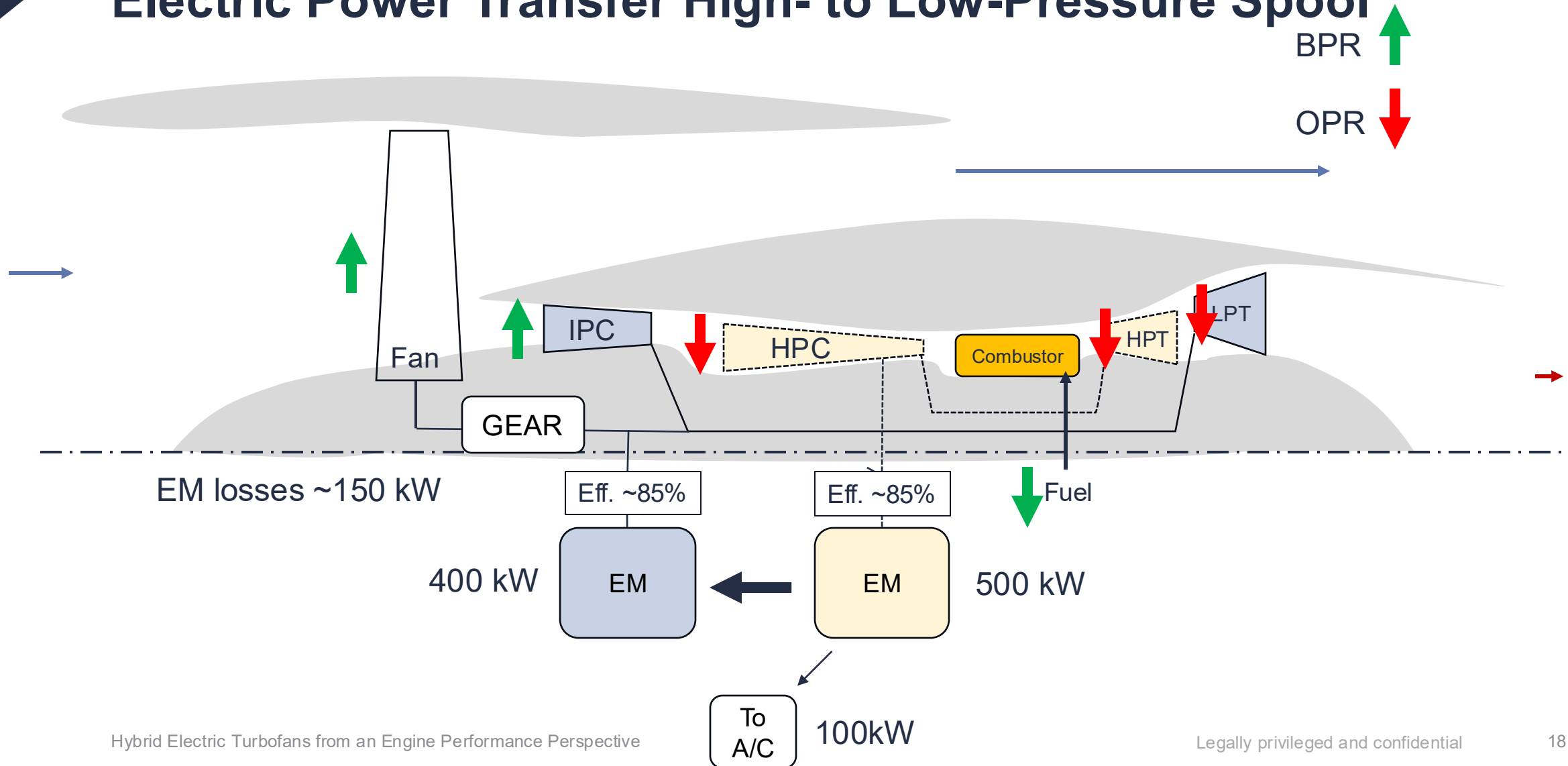
Conventional Turbofan (single aisle aircraft, mid cruise)



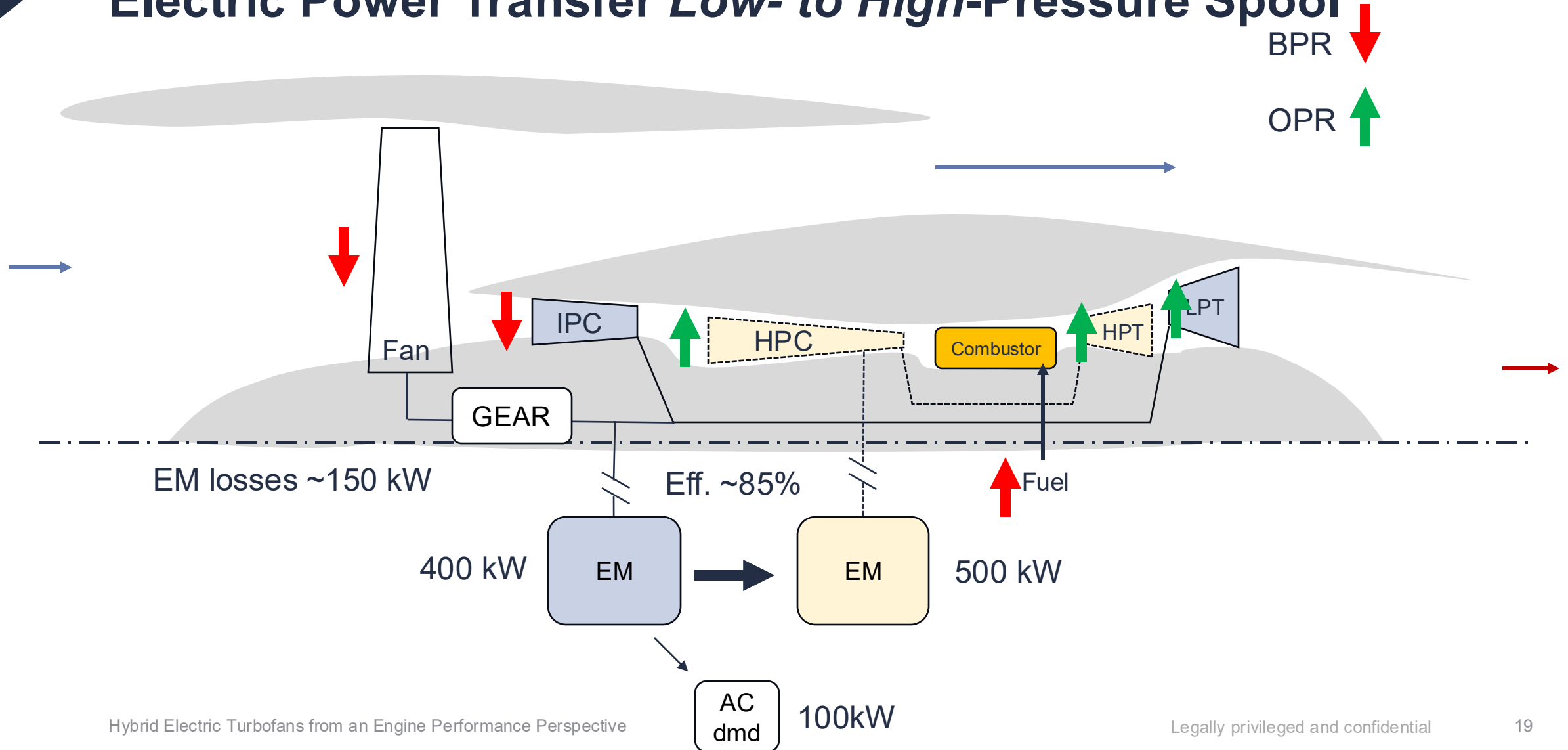
More Electric Turbofan Architecture



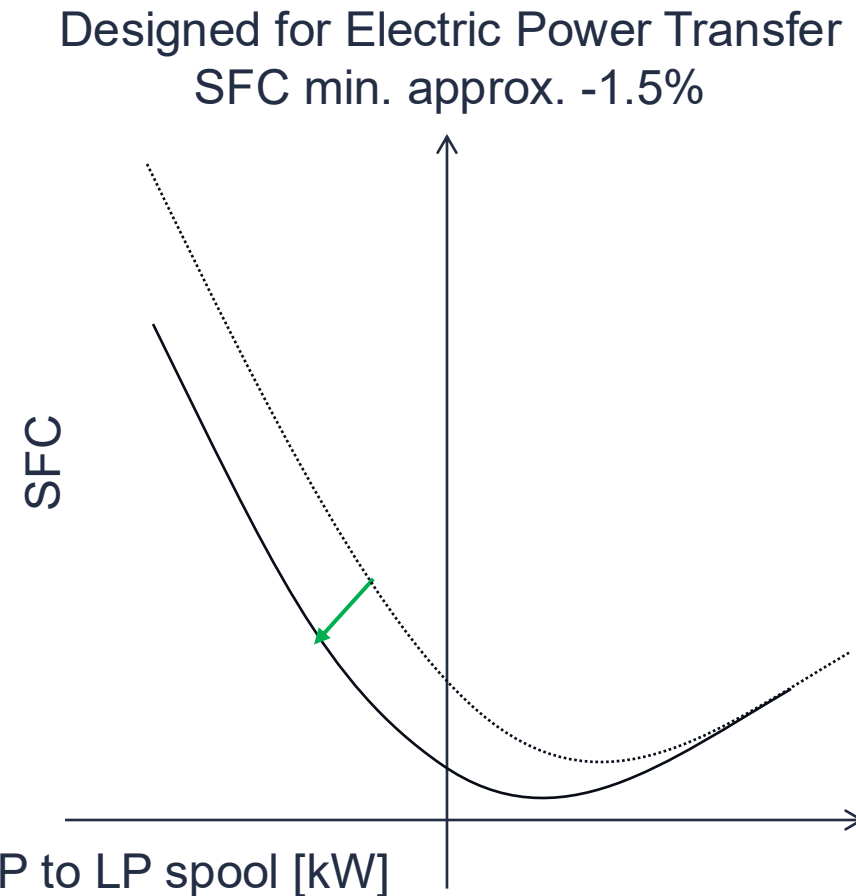
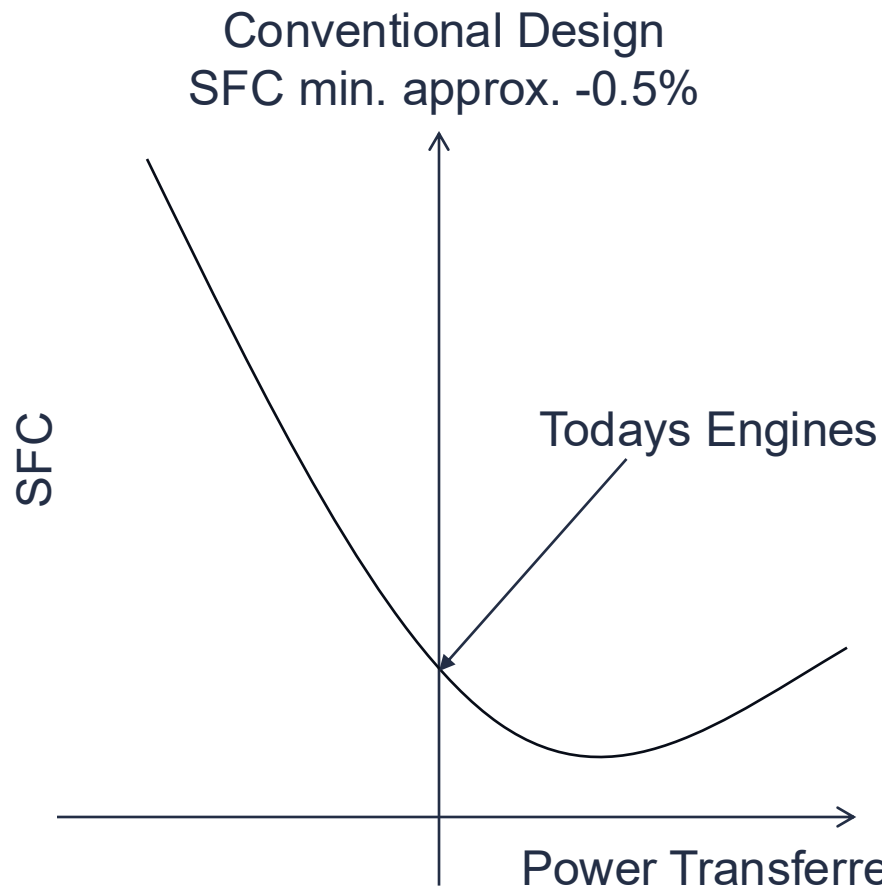
Electric Power Transfer High- to Low-Pressure Spool



Electric Power Transfer *Low- to High-Pressure Spool*



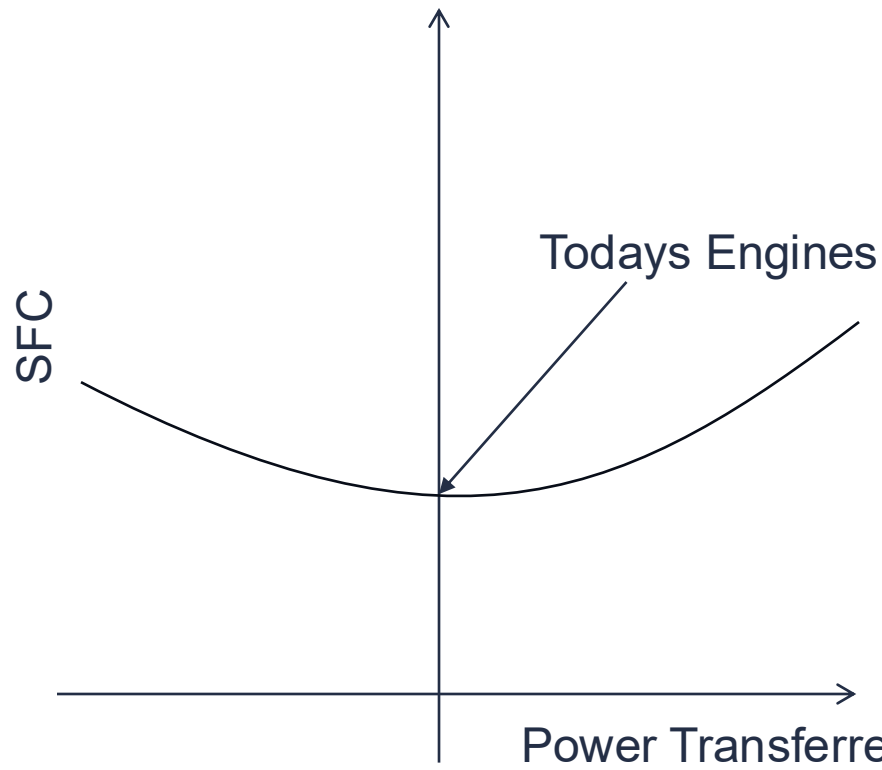
So larger electric machines would be even better?



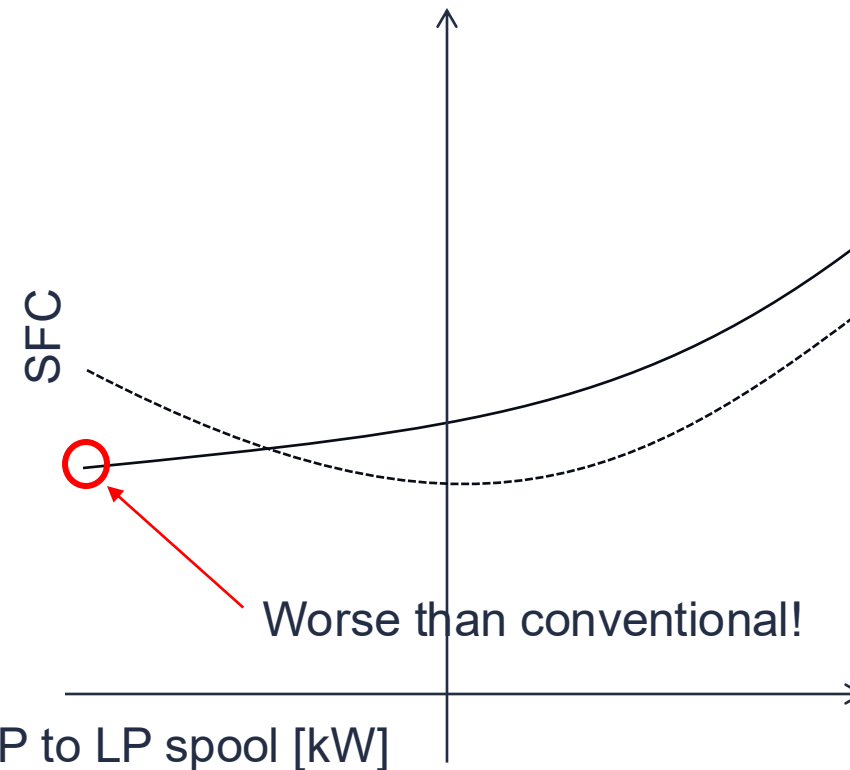
Different Behaviour in Other Flight Conditions

Take-off End of Runway

Conventional Design
SFC min. approx. 0%



Designed for Electric Power Transfer
SFC min. approx. +0.2%



Summary

Hybrid electric turbofan show...

- **...promise for decreasing cruise SFC**
 - Allow for adapting the engines BPR vs. OPR to the situation
- **...will likely require new engine designs rather than refits**
- **...many questions still left to answer**
 - Is there a benefit to including large capacity batteries?
 - How is operability kept in case of an EM failure?
 - What is the penalty of long-range battery capacity for short hop flights?

Thank you for attending!

