EXFAN

Novel recuperation system to maximize EXergy From ANergy for fuel cell powered geared electric aircraft propulsion system

Innovative Aircraft Heat Exchanger Integration for Hydrogen-Electric Propulsion

AIAA SciTech 2025 – ClimAvTech Session

Univ. Prof. Dr.-Ing. Martin Berens (BMK Endowed Professorship for Innovative Aviation Technologies)

TU WIEN

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Partners & Goal

- The exFan consortium is a multidisciplinary team and comprises of 10 partners from 4 countries
- Project Duration: 48 Months
- Project Start: 01.12.2023

The goal of the project **exFan** is to develop a concept for a novel **thrust generating heat dissipation and recuperation system** included in a **geared electric fan propulsion system** of mega-watt class that is powered by **hydrogen fuel cell** technology up to TRL 3.

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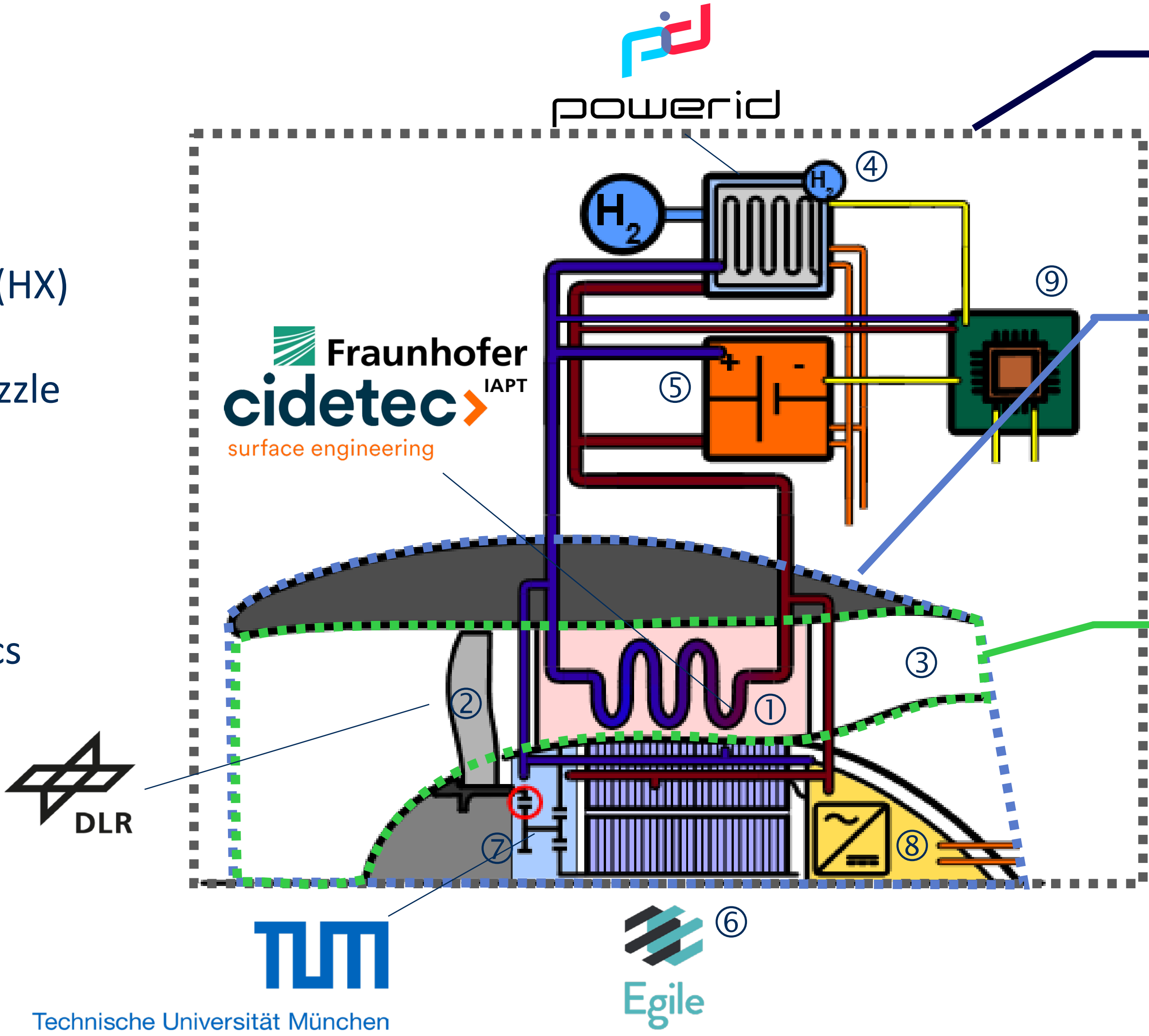
Scope

① Heat Exchanger (HX)
② Fan stage
③ Variable area nozzle
④ Fuel cell
⑤ Battery
⑥ Electric motor
⑦ Gearbox
⑧ Power electronics
⑨ Controller



Propulsion System

The Propulsion system consists of all shown components both inside and outside the nacelle

exFan

The exFan combines all components that will be directly installed inside the nacelle

Heat Propulsor

The Heat Propulsor consits of the internal flow-path (diffusor, fan, nozzle) and the heat exchanger

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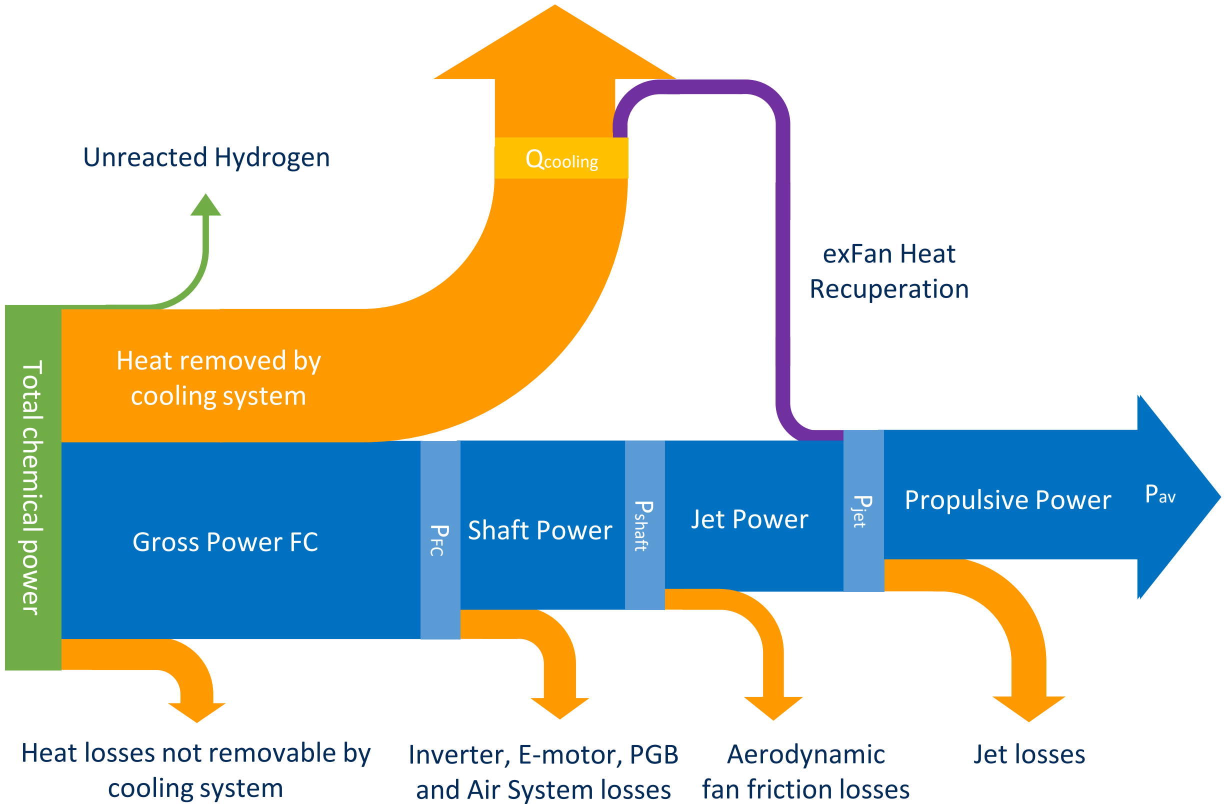
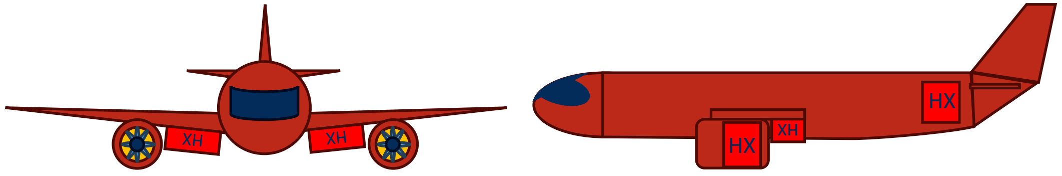
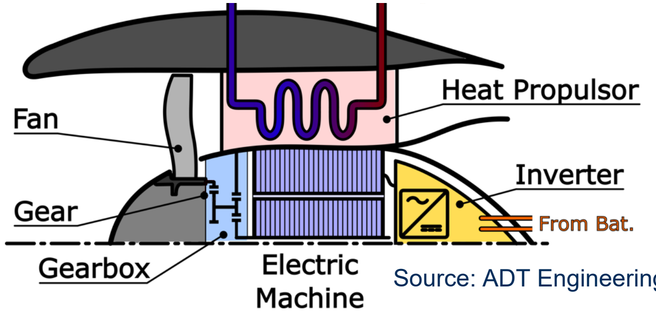
Fuel cell system heat rejection



Source: Based on https://doi.org/10.3390/membranes10050099





Source: ADT Engineering

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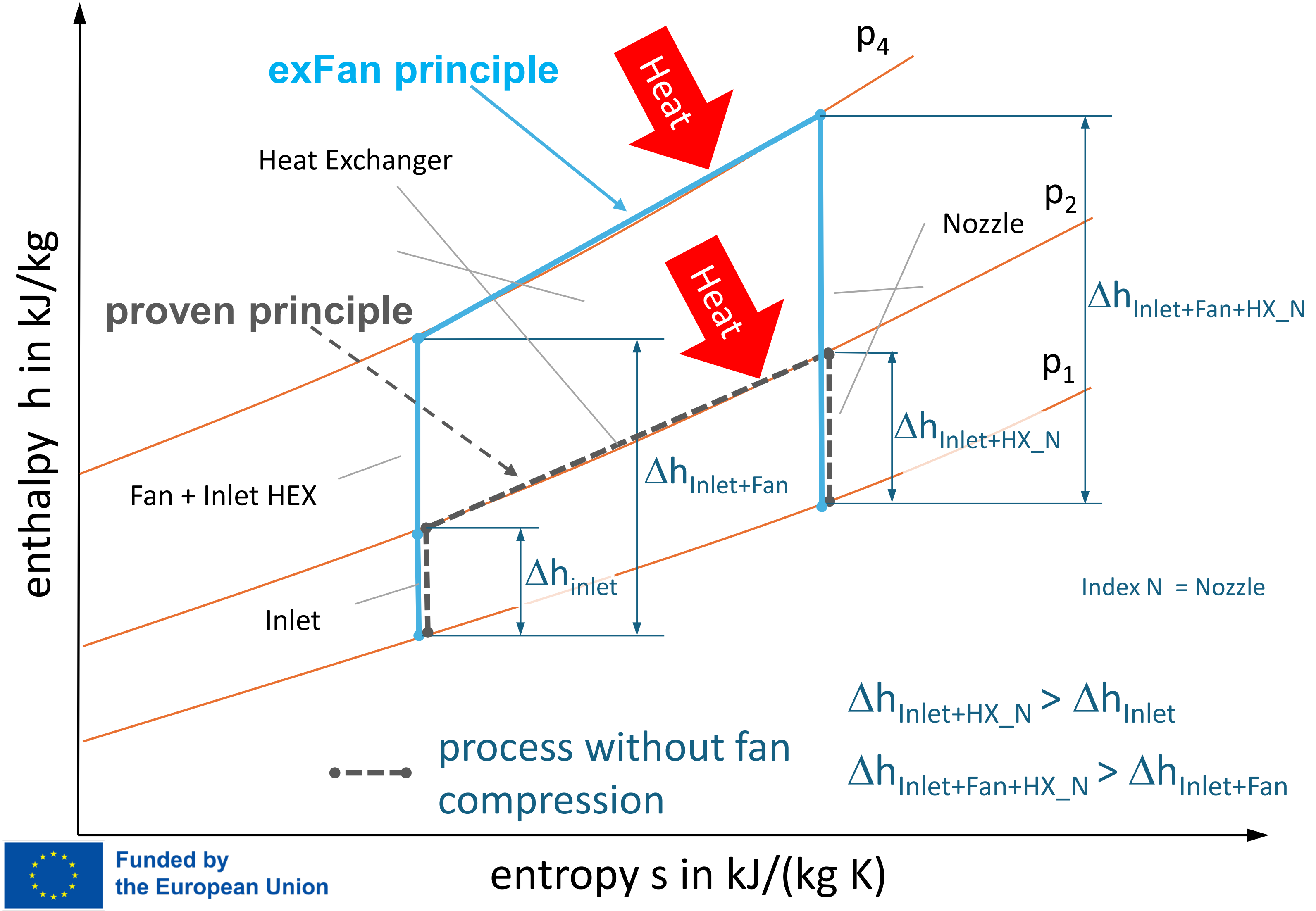
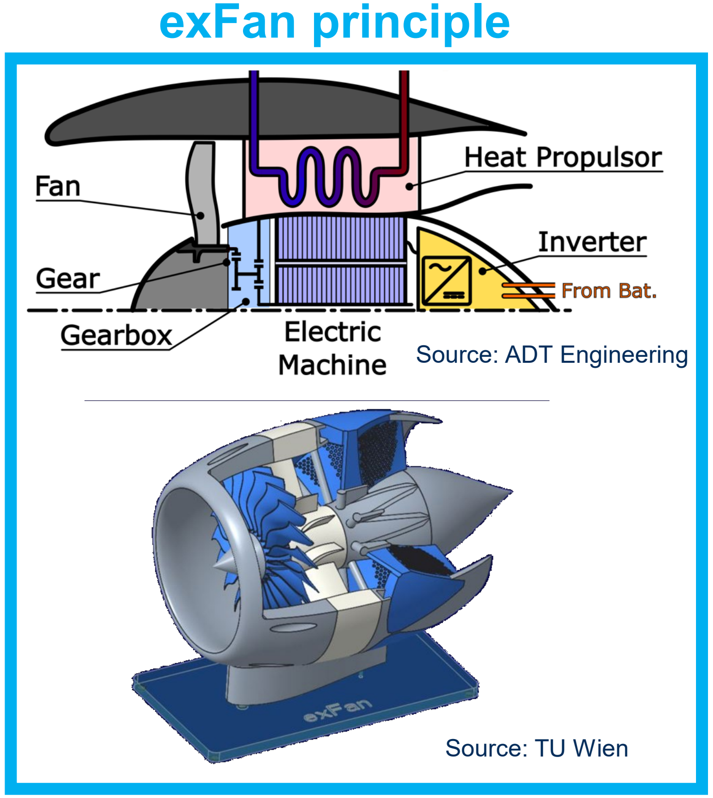
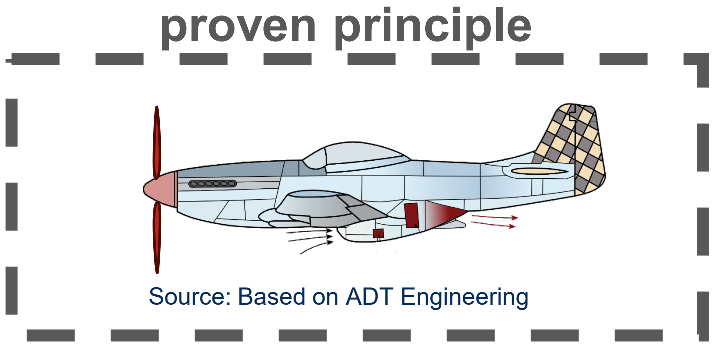
Proven principle vs exFan principle (ideal)







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Basic Concepts

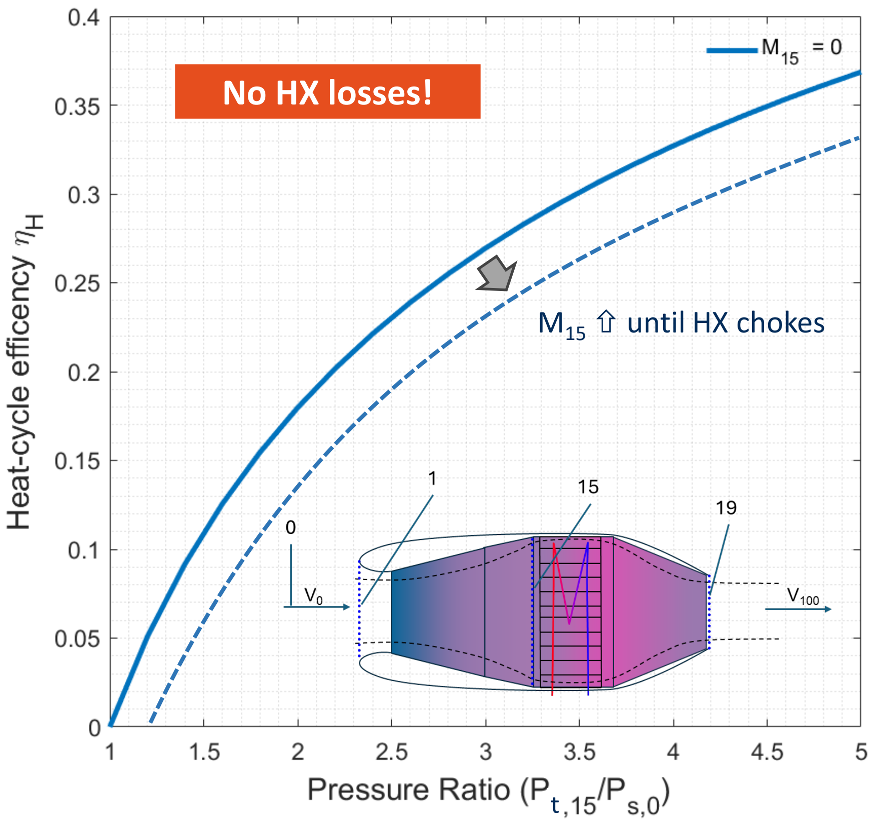
- Model of an installed HX with no losses and simplifications:

$$\eta_H = \frac{Kinetic\ power\ recovered}{Total\ heat\ added} = 1 - \left(\frac{P_{t,15}}{P_{s,0}}\right)^{\frac{1-\gamma}{\gamma}}$$

- Effectiveness of rejected heat conversion into kinetic jet power depends on nozzle pressure ratio $\left(\frac{P_{t,15}}{P_{s,0}}\right)$!
- Recuperated kinetic jet power depends on heat rate $\dot{Q}_{PEMFC}$, not on temperature.

$$\eta_T = \frac{Added\ useful\ thrust\ power}{Total\ heat\ added} = \eta_H \cdot \eta_j$$

$$\eta_j = \frac{Propulsive\ power}{Kinetic\ jet\ power}$$



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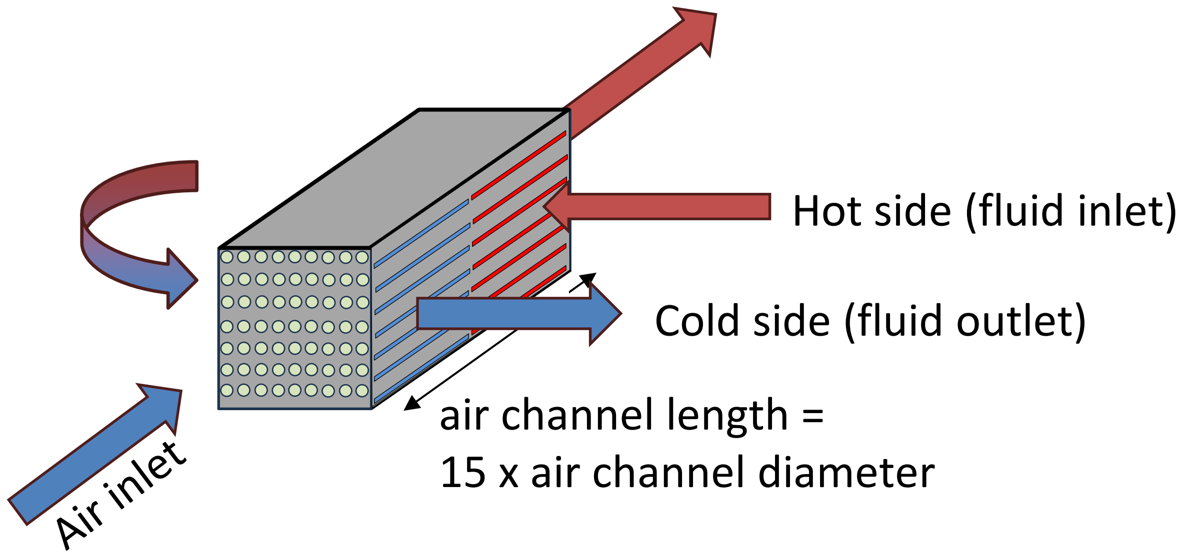
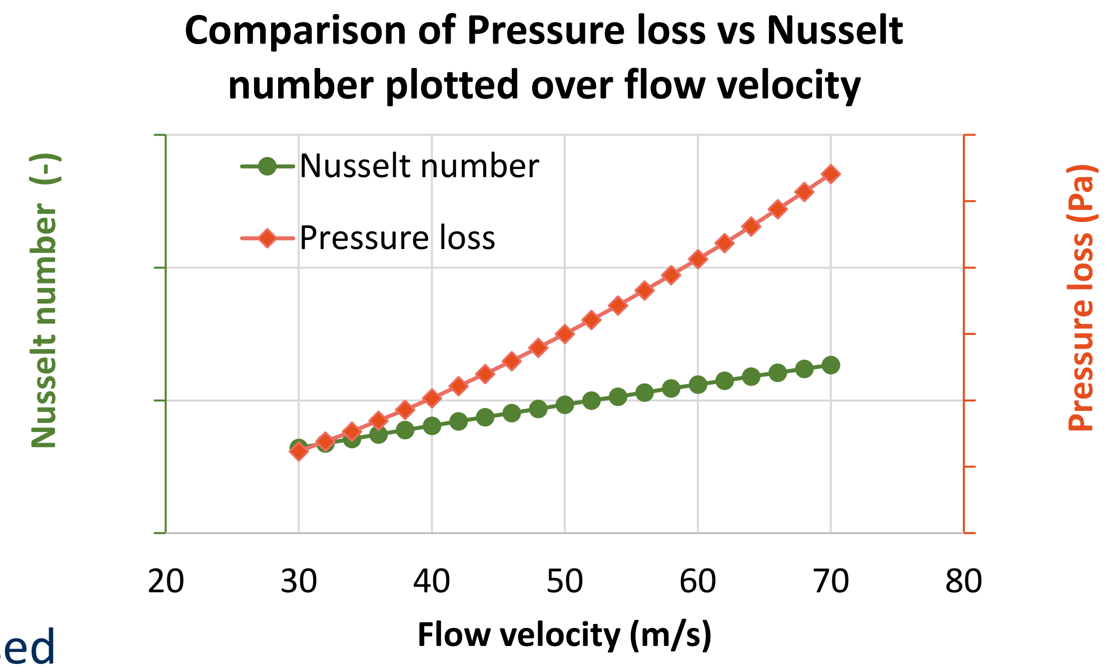
Source: J. V. BECKER und D. D. BAALS, „The Aerodynamic Effects of Heat and Compressibility in Internal Flow Systems, and High-Speed Tests of a Ram-jet System.“, NACA Rept. 773, 1943.

Basic Concepts





- Pressure losses outgrow the advantage of the increased Nusselt numbers with increasing flow velocity.
- It is advantageous to decrease the flow velocity and increase the HX air side surface area instead.

Nusselt number: Indicates how much heat is transferred to a fluid via a heat transfer surface.

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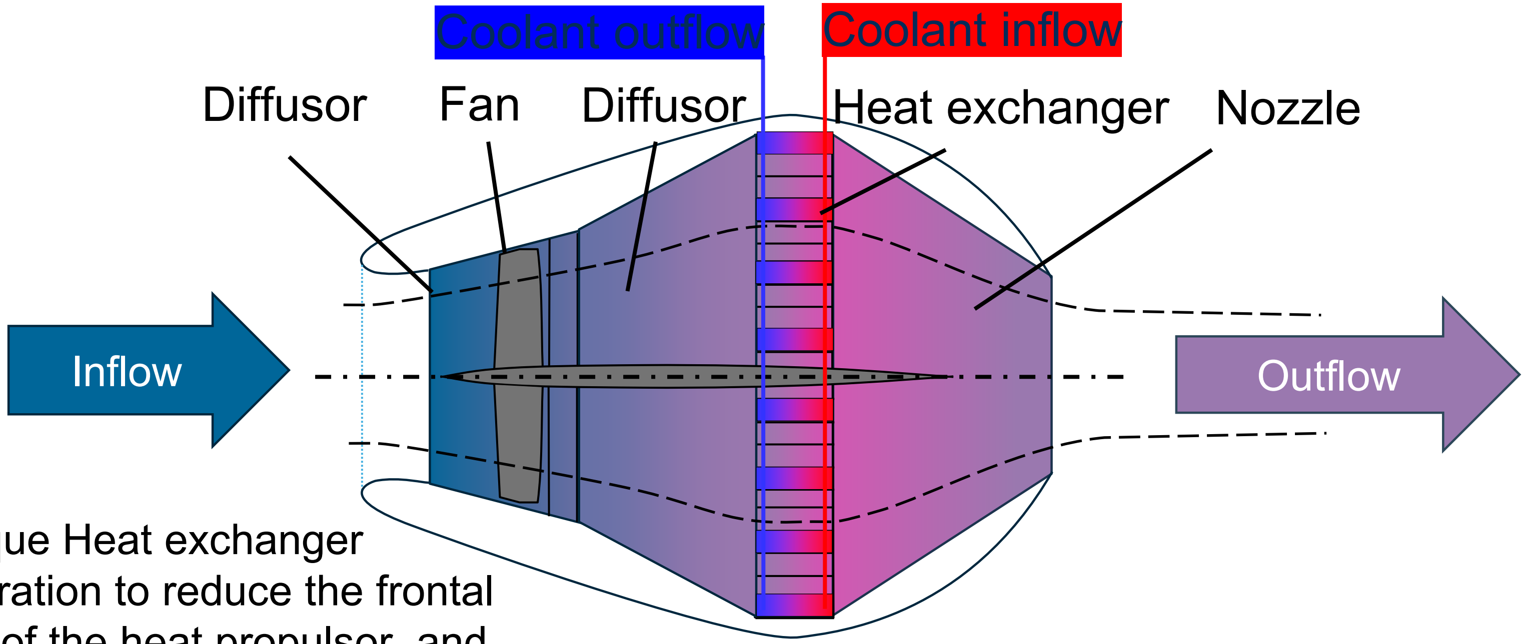
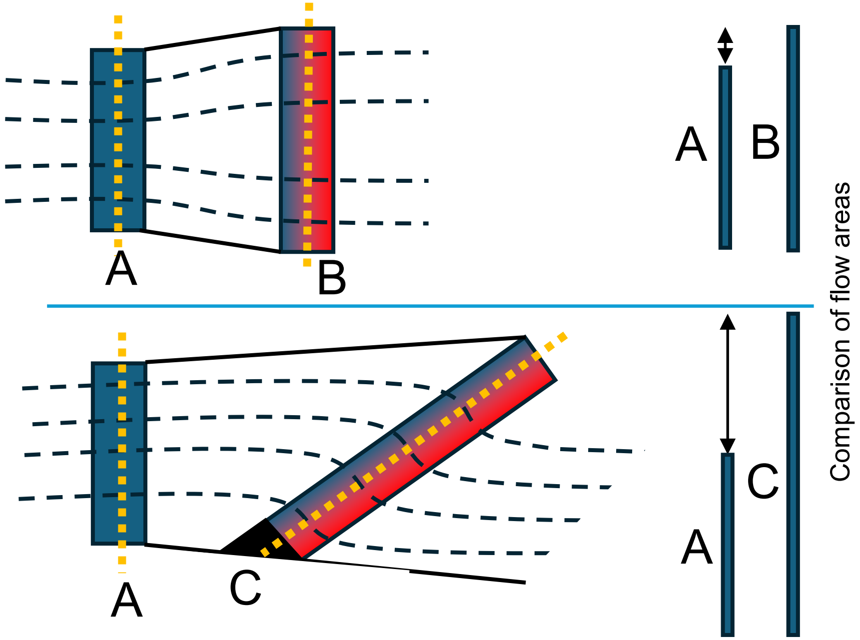
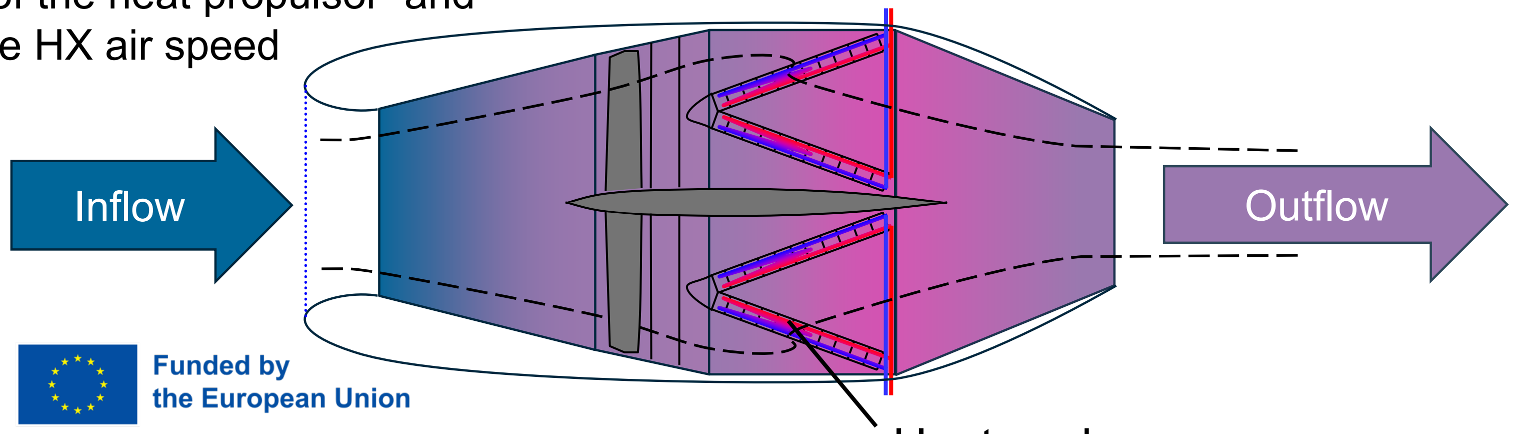
Challenge of heat exchanger integration



Maximizing the HX frontal area (B, C) w.r.t. fan area (A) to reduce airside flow Mach numbers by diffusion in order to reduce pressure losses



Oblique Heat exchanger integration to reduce the frontal area of the heat propulsor and reduce HX air speed



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Parameter Study - Results

- Transfer efficiency
  - contains fan and HX losses (but no others!) and
  - ram jet effect
- Fully rubberized model: Component sizes adapted to operating conditions

ISA temperature deviation (K)	0.0
Freestream Mach number	0.78
Fan inlet Mach number	0.5
Fan polytropic efficiency	0.85
Fuel cell and electric drive combined efficiency	0.5
Ratio of HX air inlet to fan inlet areas	3.0
Hot side inflow temperature (°C)	80
Net thrust (kN)	Const.

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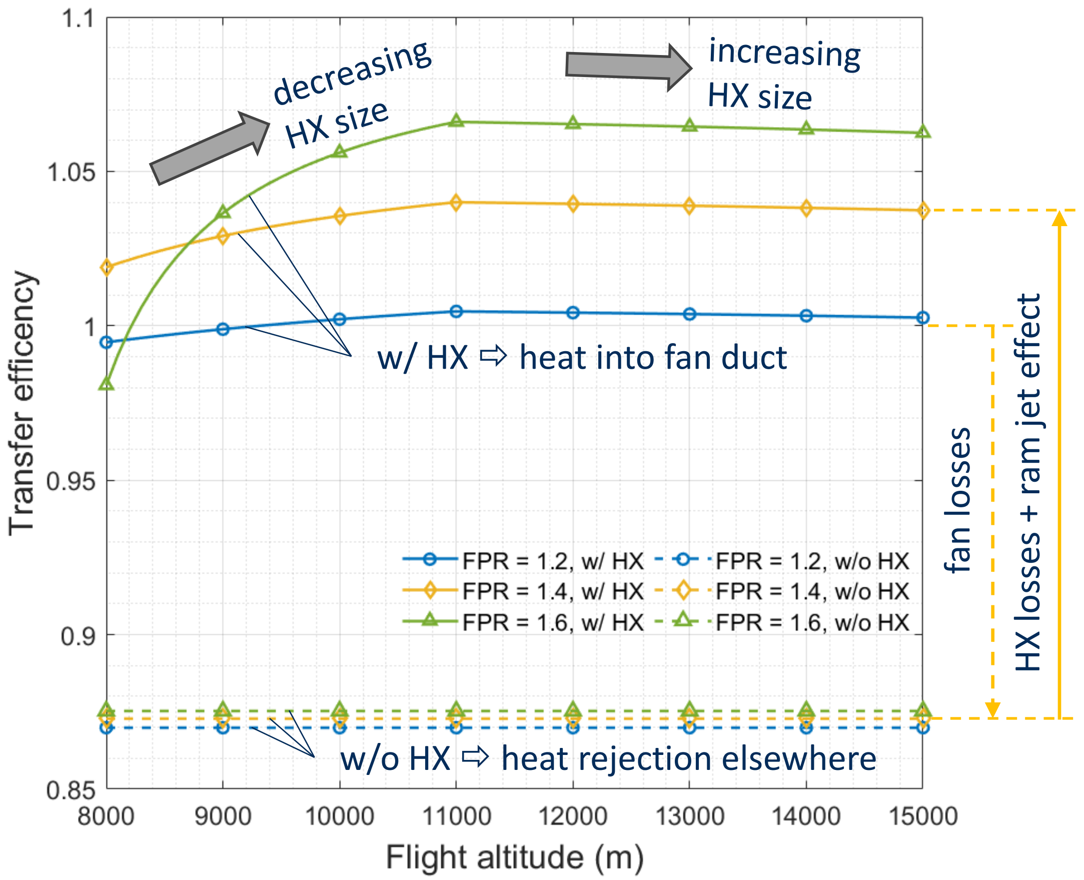
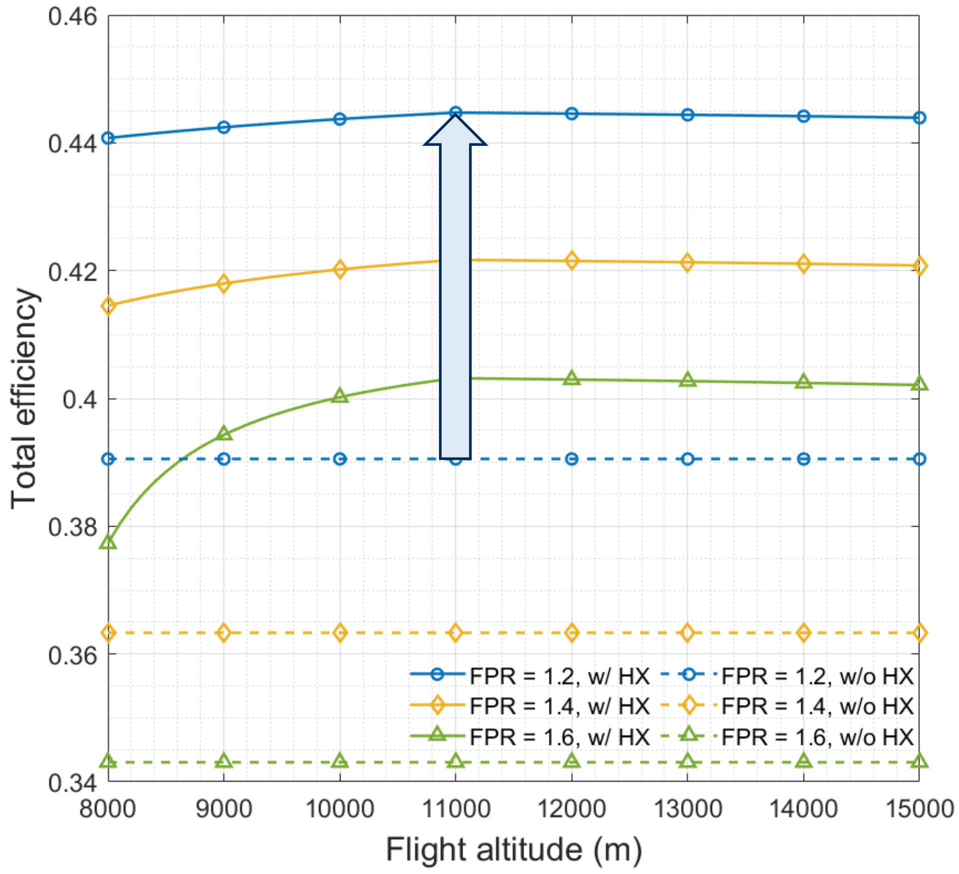


$$\eta_{trans} = \frac{P_{kin,j}}{P_{br}} = \frac{Kinetic\ jet\ power}{Power\ at\ fan\ shaft}$$

Parameter Study - Results

- Total Efficiency gains
- Diagram example:
  - FPR = 1.2
  - H = 11 km
- Ram jet potential considering losses in terms of total efficiency:
  - Net gain: + 5.4% points
  - + 13.9% w. r. t. “w/o HX” case



$$\eta_{tot} = \frac{P_{av}}{P_{Fuel}} = \frac{Propulsive\ power}{Fuel\ power}$$

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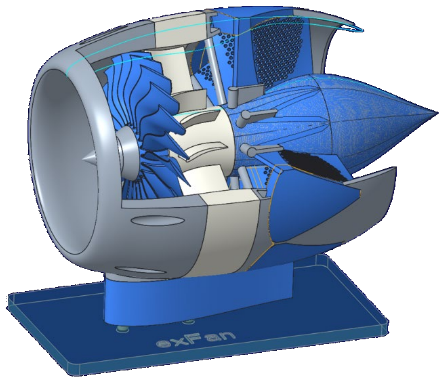
Summary and Outlook

Parameter Study Outcomes/Corroborations

- Ram jet effect increases with flight Mach number
- Thermodynamic sweet spot
  - Heat in combined fan and ram jet compressed air reward increased fan nozzle pressure ratios
  - This partially offsets the trend towards lower FNPR's for increased propulsive efficiency
  - Tropopause altitude
- Heat exchanger size depends
  - on coolant temperature ("heat quality") and
  - installed system power / heat load
- Net benefits by ram jet effect even when pressure losses taken into account (cruise $M_0 = 0.8$)
- Nacelle integration is principally possible!

This is an "artists impression" of a nacelle type integration



Outlook

- Challenges:
  - Match sea level take off and cruise req.'s
  - Hot day take off
- Studies (ongoing and later):
  - Nacelle external drag, masses, A/C perfo, costs, LCA
  - Low and High Temperature PEM Fuel Cells
  - Heat quality improvement by heat pump for Low Temperature PEM Fuel Cell
  - Air flow path CFD analysis and optimization: Intake, (Var. Pitch) Fan, Diffuser, HX, Var. Area Fan Nozzle.

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EXFAN

„The challenges of the industry are huge, but so are the opportunities.“

Univ.-Prof. Dipl.-Ing. Dr.-Ing. **Martin Berens**, MSc
BMK Endowed Professorship
TU Vienna, Institute of Engineering Design and Product Development E307
Lehárgasse 6 / BD 03 B33 / 1060 Vienna / Austria
T: +43 1 58801 **30772**
M: +43 664 60588 2105
martin.berens@tuwien.ac.at

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The EXFAN team

Project Coordinator

cidetec
surface engineering

Technical Coordinator

ADT engineering
Advanced Drivetrain Technologies

Research Coordinator

TU WIEN
TECHNISCHE UNIVERSITÄT WIEN

Project Partners

Egile

easn
Technology Innovation Services

Fraunhofer
IAPT

IRES
Innovation in Research & Engineering Solutions

TUM
Technische Universität München

DLR
Deutsches Zentrum für Luft- und Raumfahrt

powerid

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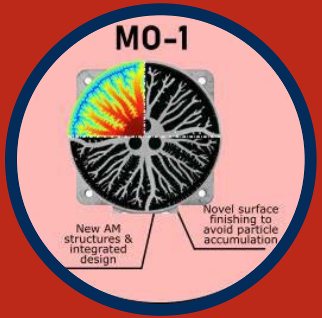
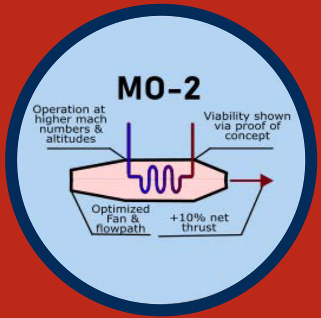
Main Objectives



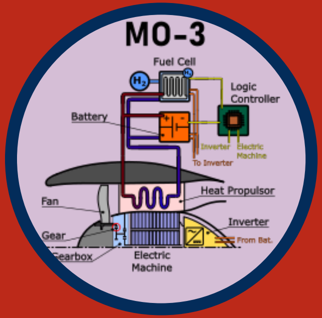
Heat dissipation

- Heat exchanger design
- Surface design



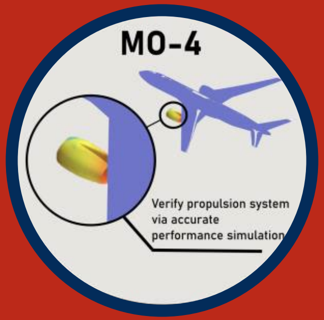
Recuperation Technology

- Concept of operations
- Interaction investigation
- Flow path design
- Proof of concept



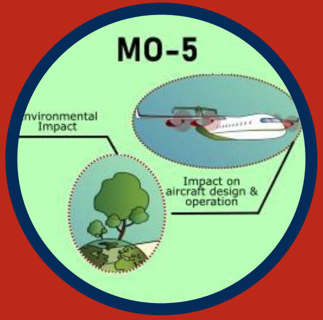
Thermal Management System

- Thermal manage-ment concept
- Prop. system layout
- Enhance heat quality
- Enable hot day T/O



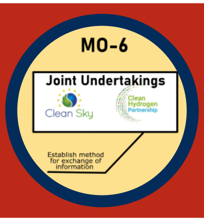
System Simulations

- Creation of accurate simulation models
- Verify exFan system (steady state sim.)
- Analyse the transient behaviour of the propulsion system



Impact on Operation and Environment

- Impact of aircraft design & operation
- Life cycle analysis



Information Exchange

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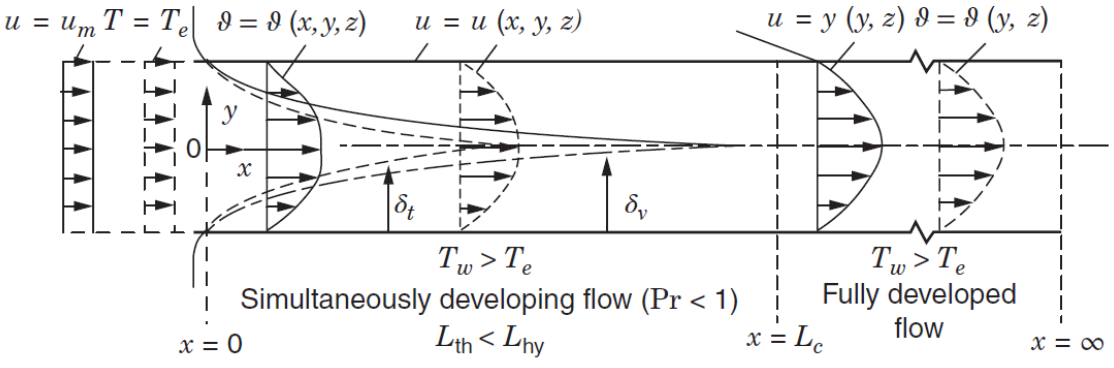
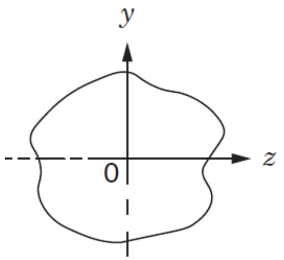
Parameter Study - Assumptions



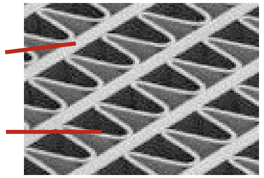


Present parameter study

Source: Sekulic D.P., Shah R.K.: Fundamentals of heat exchanger design, Wiley, 2003

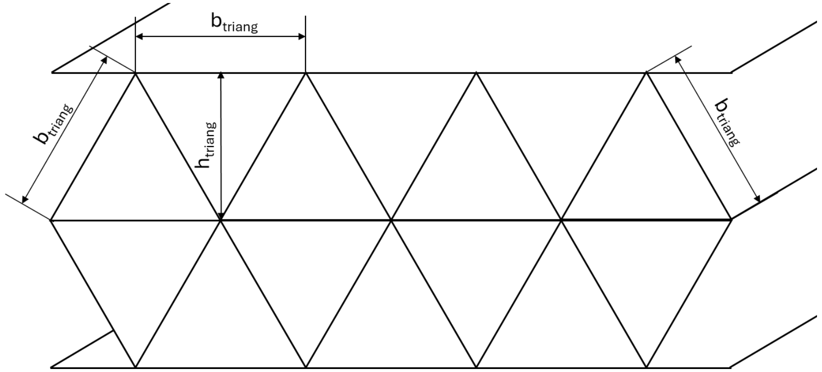
plate (aka tubes => liquid coolant channels)

fins form air flow path



HX air side settings

- Friction losses in the HX
- 1D-Modelling (based on hydraulic diameter)
- Counter flow compact plate and fin HX (real HX may be of crossflow type)
- Two fluid, direct transfer, single pass
- Blockage due to coolant plate/tubes is neglected
- Fully developed turbulent flow, Prandtl number Pr = 0.72



b_{triang} = 10 mm

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Parameter Study - Results

- HX losses decrease with hot side inflow temperature because of reduced HX size ⇨ Efficiency increases

	Take Off	Cruise
Flight altitude in ft	0.0	35000
ISA temperature deviation in K	0.0	
Freestream Mach number	0.22	0.78
Fan polytropic efficiency	0.85	
Fuel cell and electric drive combined efficiency	0.5	
Fan total pressure ratio (FPR)	1.2 – 1.6	
Net thrust in kN	120.143	23.020
Fan Inlet Mach number	0.5	
Ratio of HX air inlet to fan inlet areas	3.0	

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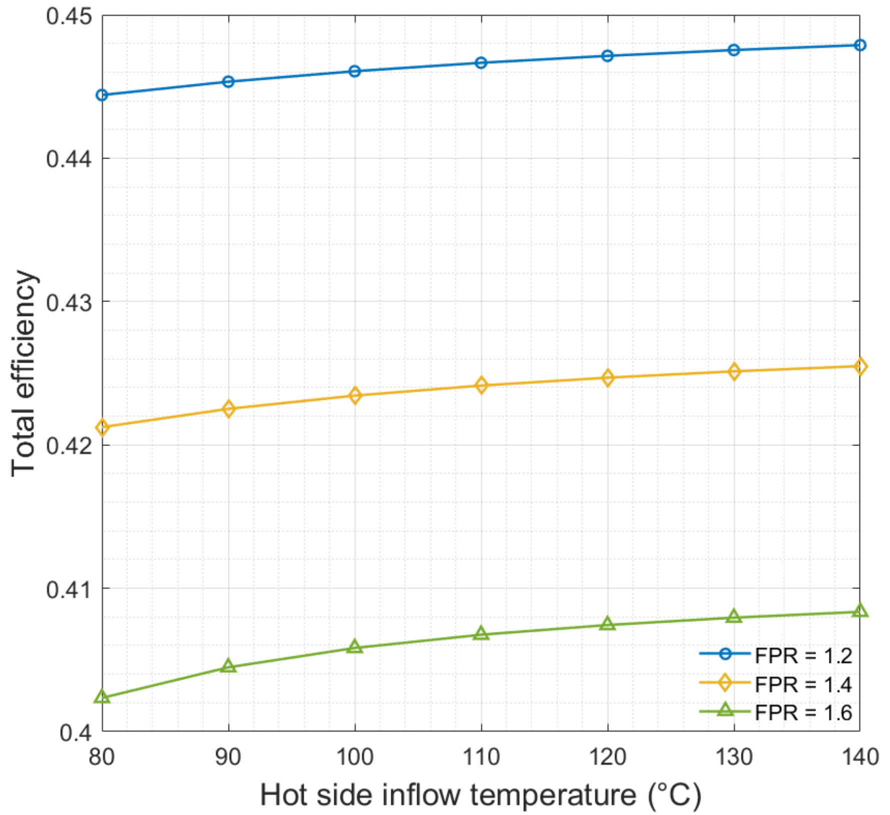
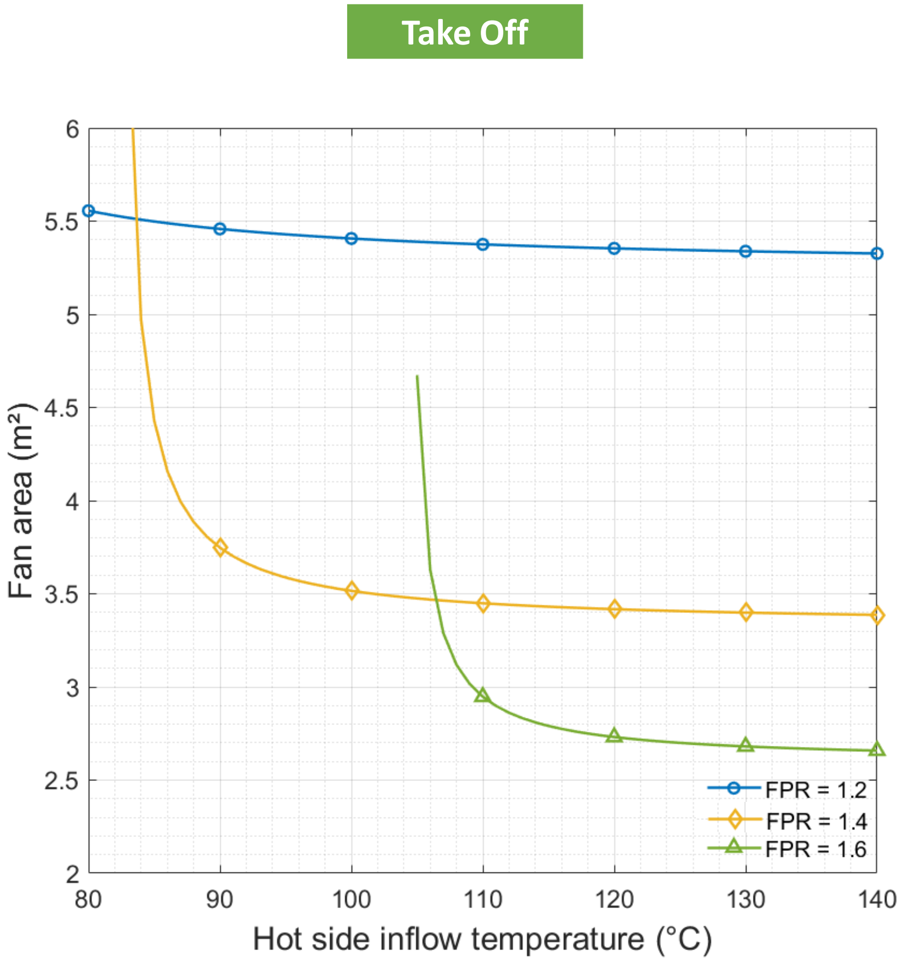
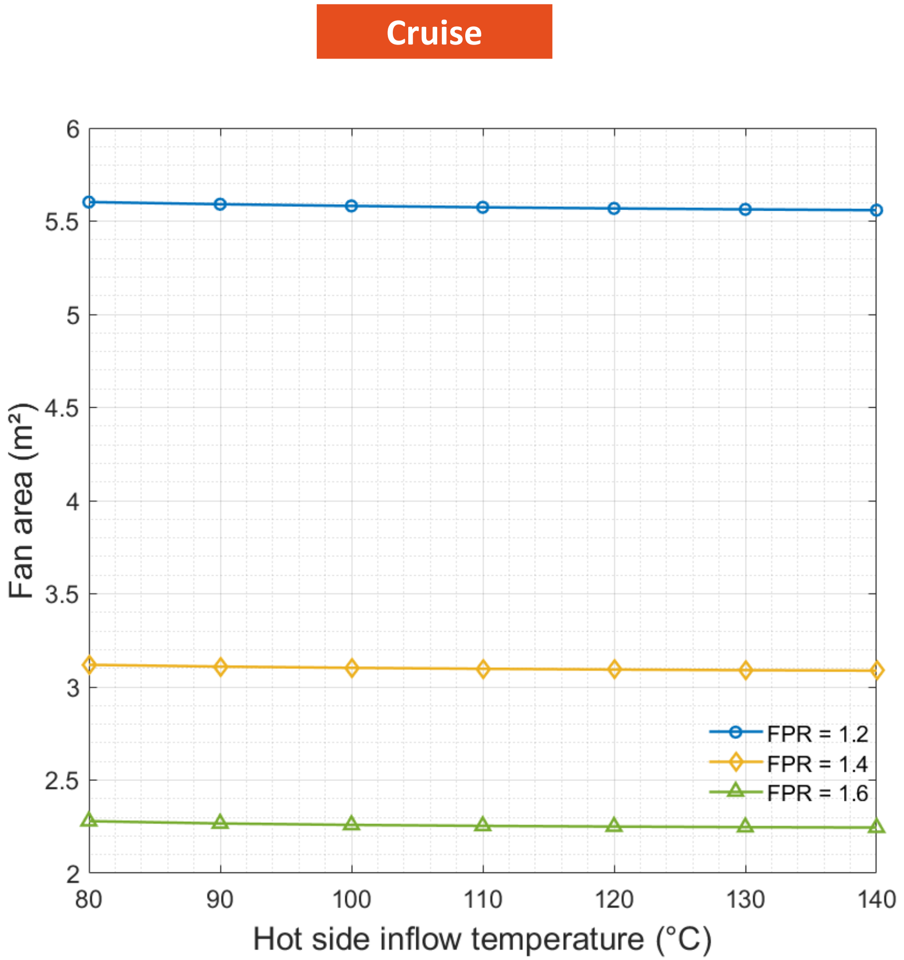
Cruise



$$\eta_{tot} = \frac{P_{av}}{P_{Fuel}} = \frac{Propulsive\ power}{Fuel\ power}$$

Parameter Study - Results





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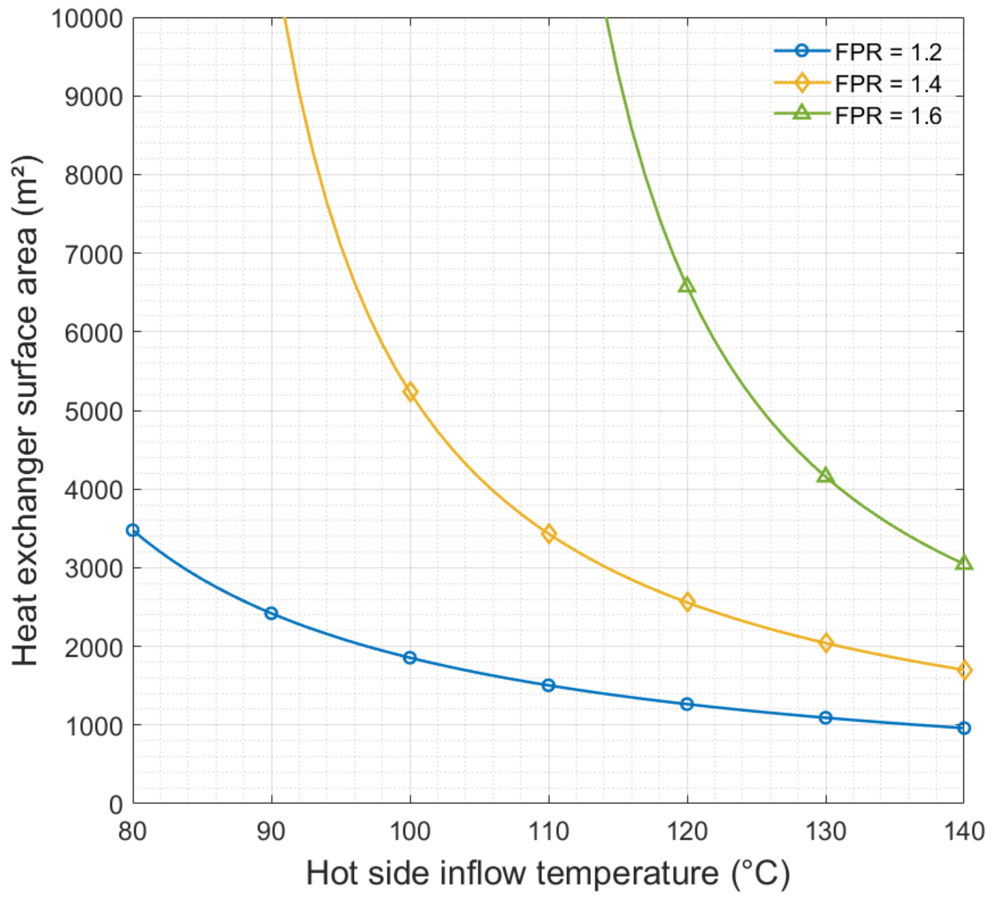
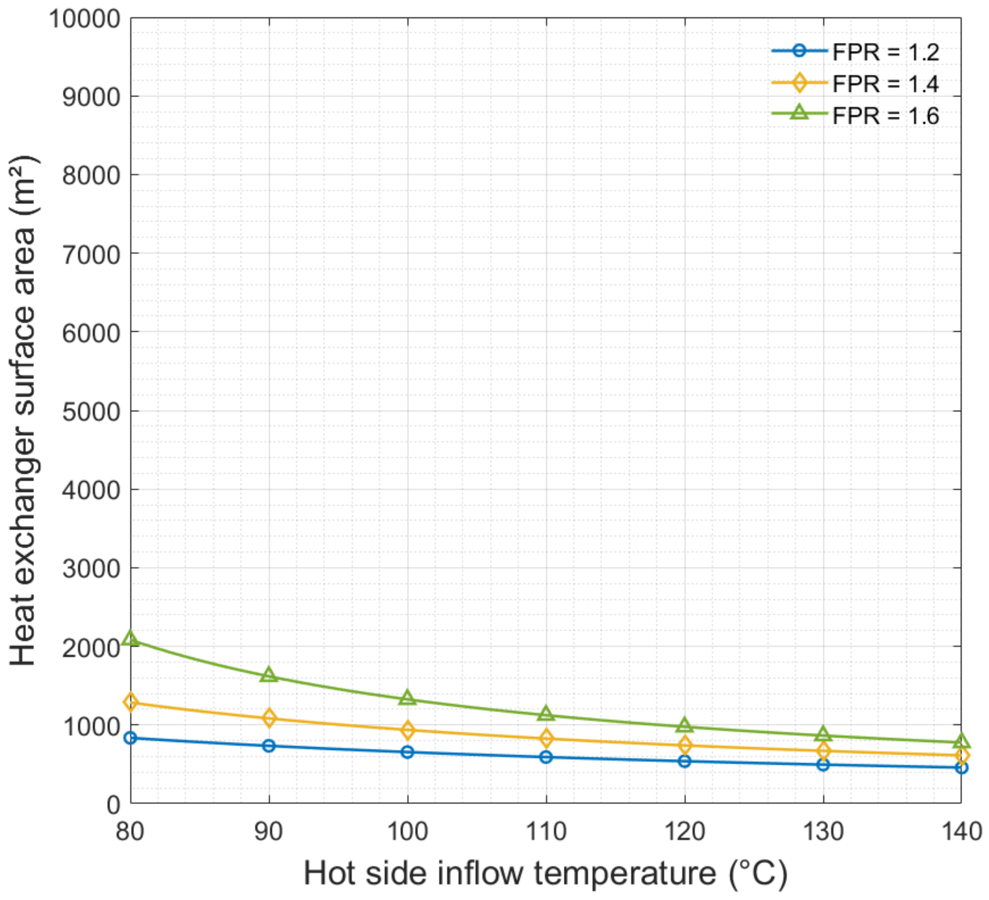
Parameter Study - Results

Take Off



Cruise



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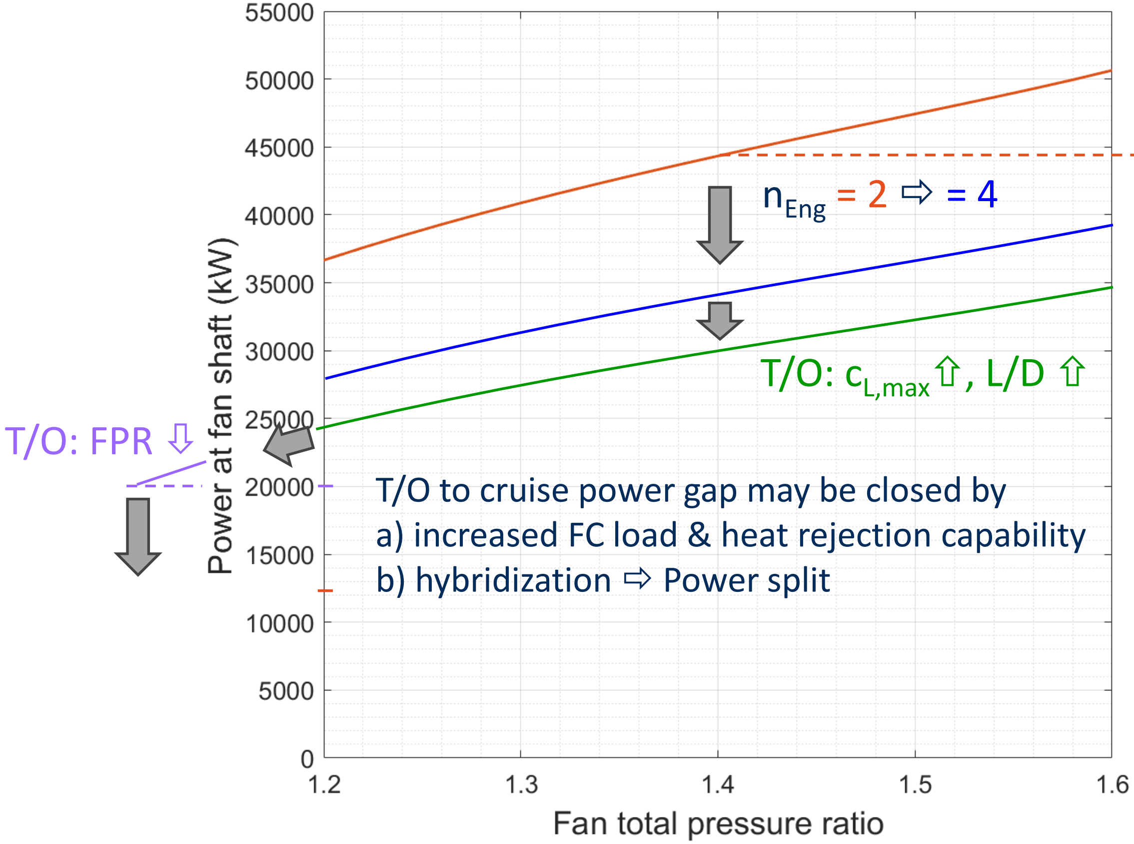
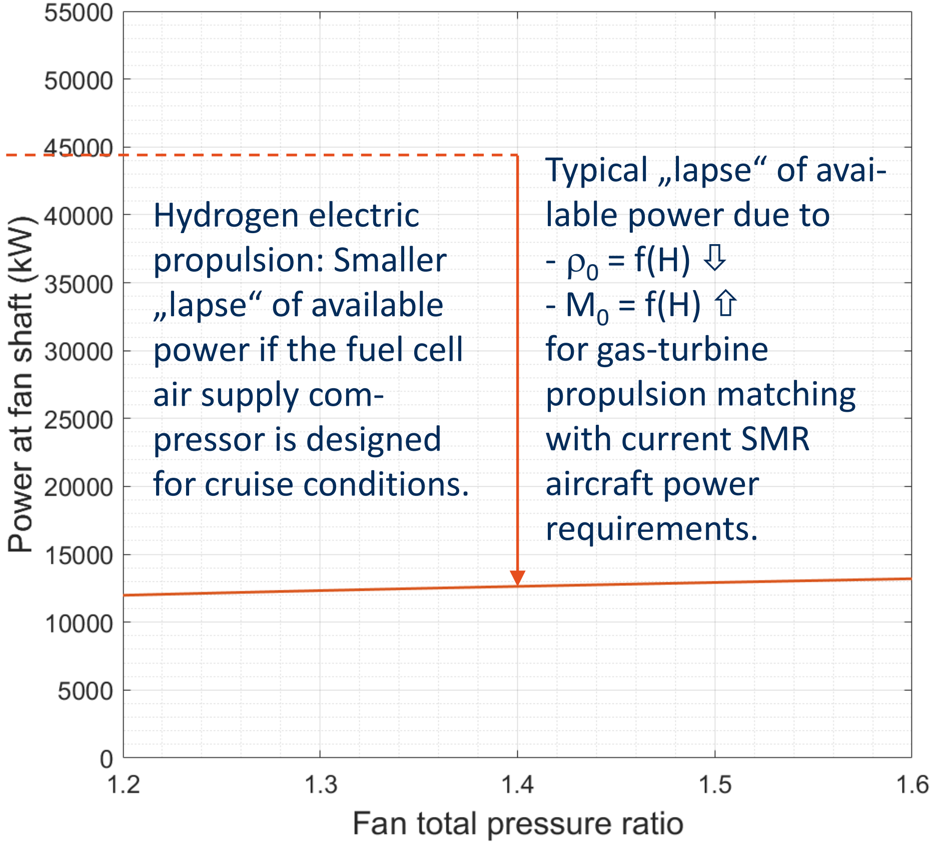
Conclusions and Outlook

Take Off

Cruise





Coolant temperature 120°C!

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