Fuel-Cell-Powered Fan Design Studies with Heat Utilization

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Motivation

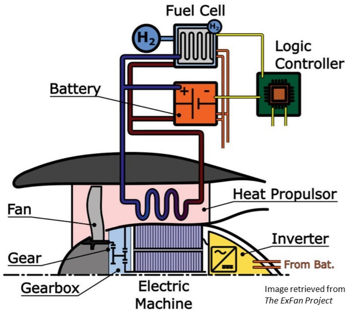
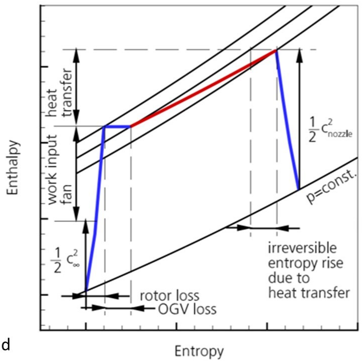


Image retrieved from *The ExFan Project*

- The **exFan** project aims to develop a **novel heat dissipation and recovery system** within a **high-powered electric fan propulsion** driven by fuel cell technology.
- It incorporates a **ducted heat exchanger** using the "Meredith effect" to **generate thrust from waste heat.**
- This work investigates an **electric fan design** within a fuel-cell-driven propulsion architecture at the cycle design level, focusing on **fan and heat exchanger interactions** for optimal performance.
- Investigations are conducted on different **Fan Pressure Ratios** (FPR) and **Mach numbers** as they enter the heat exchanger (HEX).
- The study explores the **potential for thrust enhancement** through heat addition.

Thermodynamic cycle:



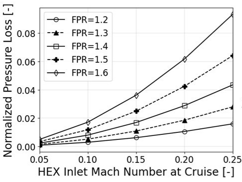
- **Ram effect** and **work** done by the **fan increase pressure** and **temperature** of incoming air.
- Compressed air **decelerates** in a divergent duct.
- **Heat added** by a heat exchanger **increases thermal energy**, resulting in **mechanical work potential** but causes pressure losses due to aerodynamic resistance.
- High-energy air expands through the nozzle, **converting to kinetic energy** and producing **thrust.**

Methodology

- Cycle design model developed within GTlab, DLR's in-house performance tool.
- Parametric studies conducted with **constant power input**, thus, also **constant heat** loads to compare additional thrust gain and total thrust levels - components sized at cruise condition (FL350, Ma 0.78).
- Further studies conducted with **constant thrust** to investigate flowpath sizing to meet Aircraft-required thrust levels at multiple operating points - HEX sized at take-off condition (ISA SLS) and fan at cruise condition

Results

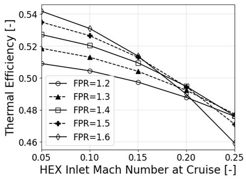
Constant Power Studies:



HEX Pressure Losses

$$\frac{P_{t,HEX\ in} - P_{t,HEX\ out}}{P_{t,HEX\ in}}$$

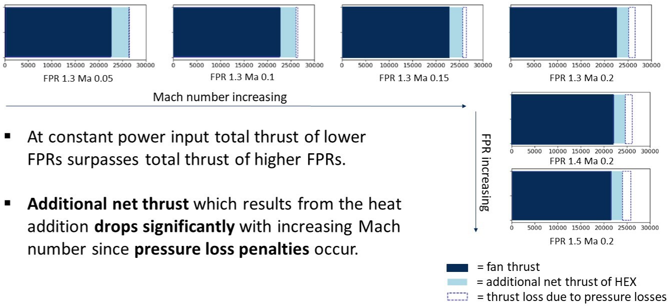
- Higher fan pressure ratios generally induce greater pressure losses.
- The **increase** of **pressure losses** with rising Mach numbers is **significantly higher** for **high fan pressure ratios.**



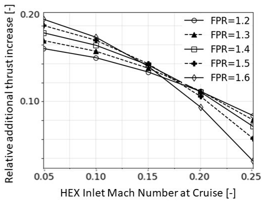
Thermal Efficiency

$$\frac{PW_{kin,jet}}{PW_{tot}}$$

- **Thermal efficiency improves** for **high FPRs** only at **low Mach numbers** because jet kinetic power, driven by jet velocity, drops due to pressure losses, which are more severe at high FPRs and high Mach numbers.



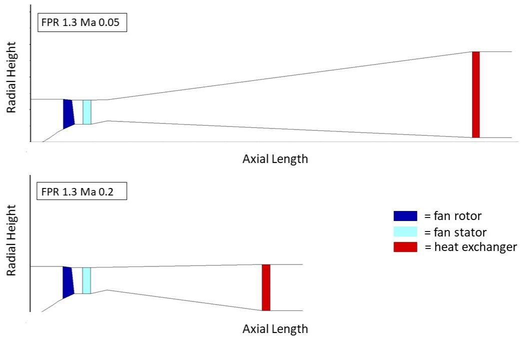
- At constant power input total thrust of lower FPRs surpasses total thrust of higher FPRs.
- **Additional net thrust** which results from the heat addition **drops significantly** with increasing Mach number since **pressure loss penalties** occur.



- **Higher FPRs** are **favorable** for **effective heat transfer**, translating to additional thrust, but the net thrust benefit is **only predominant at low Mach numbers** since high pressure losses counteract this benefit.

Constant Thrust Studies:

- The flowpath designs resulting from the performance model are presented below in same scale figures:



- **Low Mach number** designs do **require longer transition ducts** since the needed change in area for deceleration is greater and the laws of diffusion have to be obeyed to avoid flow separation.
- For constant Mach numbers, **high FPRs** inherently reduces difference in Fan Exit and HEX inlet areas, resulting in a **more compact cross-sectional size** while maintaining proportional scaling of the duct.
- Feasibility of the current integrated fan/HEX configuration is to be determined - **alternative possibilities** to **reduce Fan-Face-Mach number beyond conventional** levels **should be considered**.

Conclusion and Outlook

- While **low Mach numbers** are **require**d to achieve **reasonable** amount of **pressure losses** in the heat exchanger, **high Mach numbers are favorable for conventional fan design**.
- In terms of fan pressure ratio, **additional thrust gain is most effective** at **higher FPRs**, however rising HEX Mach number progressively damps out and reverses this trend to lower FPRs due to the associated HEX pressure losses.
- Consequently, the **study suggests** finding a **balance** between **lower Mach numbers**, **achievable diffusion**, and **higher fan pressure ratios**, while emphasizing the need to focus on component interactions to avoid compromising overall system performance.
- **Future research** will **incorporate** further assessment of **installed performance** (incl. spillage, nacelle and weight drag) as well as alternative fan designs with reduced fan-face Mach number beyond conventional levels.

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Project Partners

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