FUTure PRopulsion and INTegration
towards a hybrid-electric 50-seat regional aircraft

FutPrInt50: Main contributions and technical challenges

EASIER Workshop | 02.06.2021 | online

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This project has received funding from the European Union’s Horizon 2020 Research and Innovation programme under Grant Agreement No 875551

European Commission

Content Overview

FutPrInt50

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Main Contributions

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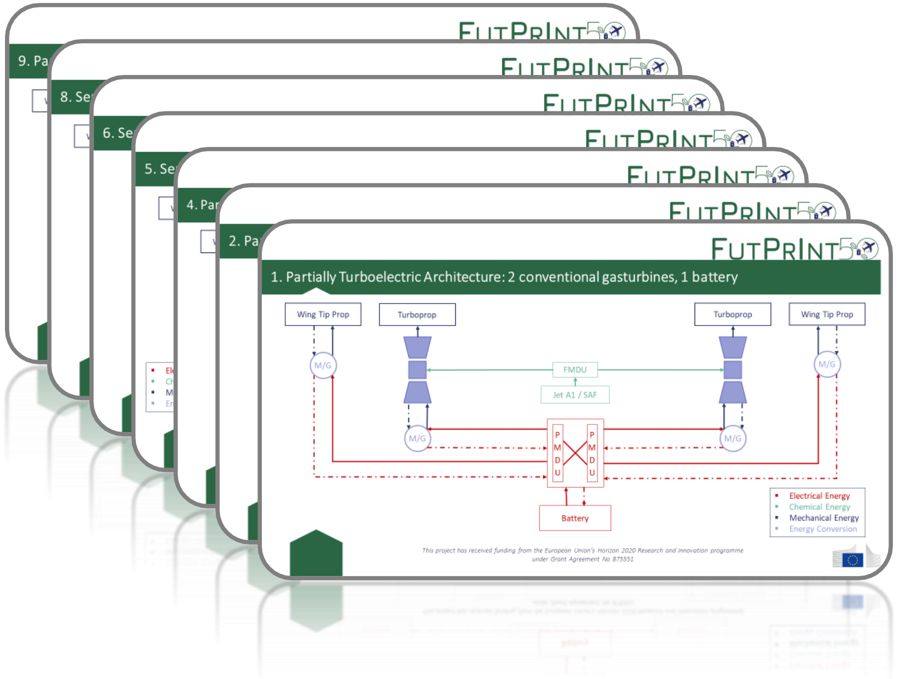
Main Contributions: Hybrid-Electric Reference Aircraft (50 Pax)

Seven Architectures defined to be investigated in FUTPRINT50



Constant Down Selection

Hybrid-Electric Reference Aircraft Model

- Feasible for EIS in 2035/40
- Focus on emissions reduction and key technologies

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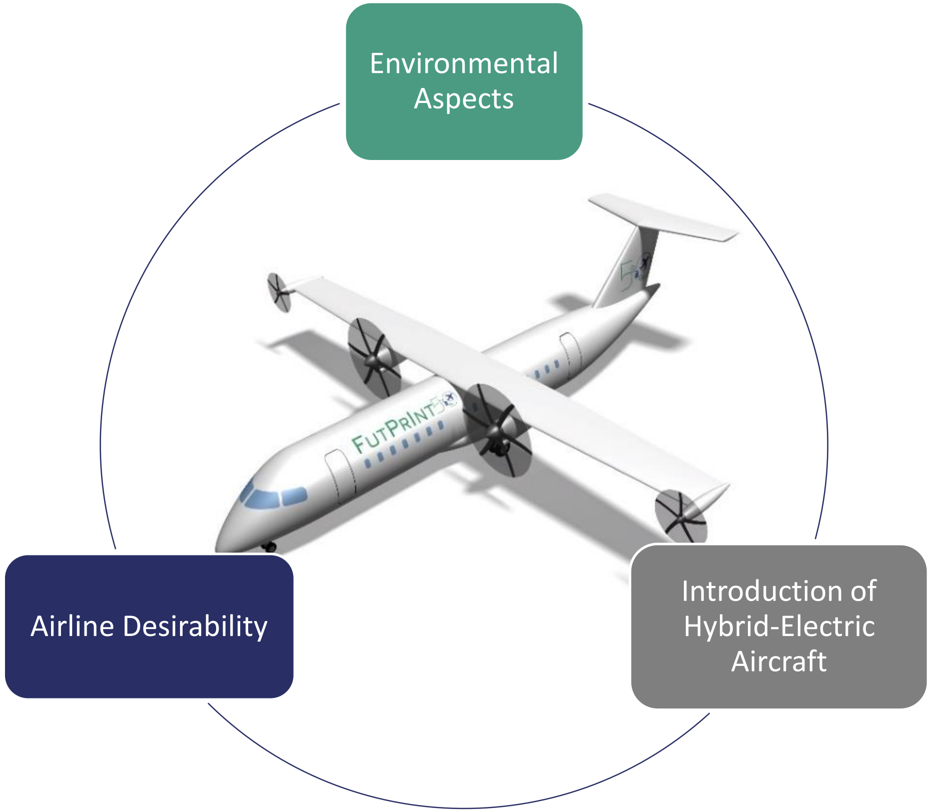
Main Contributions: Figures of Merit



The Figure of Merit will support down selecting architectures and evaluating different designs!

- CO_2 Emissions
- NO_X Emissions
- Noise Emissions
- Direct Operating Costs
- Development Risks
- Certification Challenges
- Production Aspects

$$FOM = \frac{w_{\mathrm{EI}} \cdot \left(\frac{w_{\mathrm{CO2}} \cdot \bar{f}_{\mathrm{CO2}} + w_{\mathrm{NOX}} \cdot \bar{f}_{\mathrm{NOX}} + w_{\mathrm{Noise}} \cdot \bar{f}_{\mathrm{Noise}}}{w_{\mathrm{CO2}} + w_{\mathrm{NOX}} + w_{\mathrm{Noise}}} \right) + w_{\mathrm{AD}} \cdot \left(\bar{f}_{\mathrm{DOC}} \right) + w_{\mathrm{HEI}} \cdot \left(\frac{w_{\mathrm{Devel\ op}} \cdot \bar{f}_{\mathrm{Develop}} + w_{\mathrm{Cert}} \cdot \bar{f}_{\mathrm{Cert}} + w_{\mathrm{Prod}} \cdot \bar{f}_{\mathrm{Prod}}}{w_{\mathrm{Develop}} + w_{\mathrm{Cert}} + w_{\mathrm{Prod}}} \right)}{w_{\mathrm{EI}} + w_{\mathrm{AD}} + w_{\mathrm{HEI}}}$$

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Main Contributions: Aircraft Design Toolbox

python™

SUAVE 2.2.0
An Aerospace Vehicle Environment for Designing Future Aircraft

FUTPRINT50 extends SUAVE such that it is capable to calculate:

- Energy Storage
- Energy Harvesting
- Thermal Management
- Energy Management Strategies
- Hybrid-Electric Aircraft Configurations
- Figures of Merit

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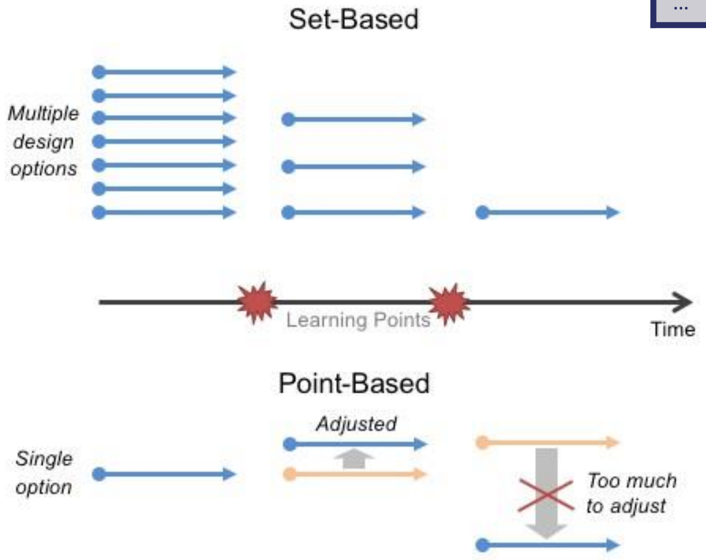
Main Contributions: Probabilistic Set-Based Design with Optimization

The principle of Set-Based Design is to **consider as many configurations as possible** from the start and discard the least desirable ones.



Parameter	Values
Degree of Power Hybridization	0-1
Energy density of Batteries	200-500 Wh/kg
Required Range	300-600 NM
Number of propellers	2, 4, …
…	…

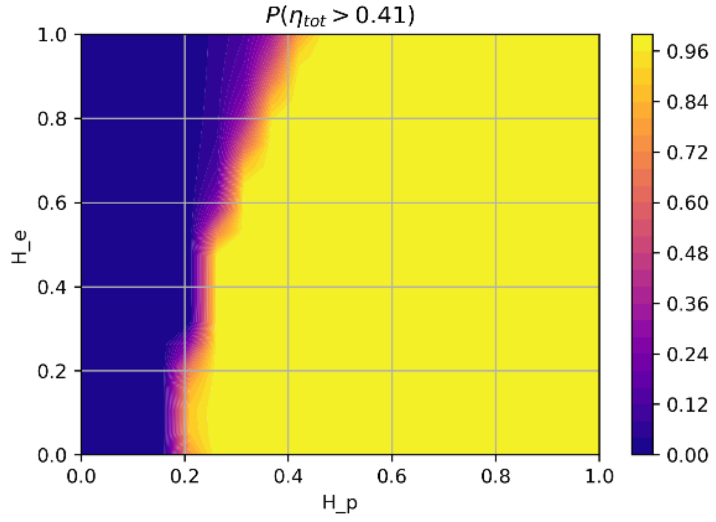
Step 1
Discretize parameters, generate combinations
Discard infeasible configurations and/or with low probability to satisfy FOM.

Step 2
Convert surviving combinations in optimisation problems.
Run optimiser, propagate uncertainties and discard least desirable/robust configurations.

Iterate and increase fidelity or update constraints/requirements

Visualization and post-processing of accepted and discarded configurations

Currently Step 1 is in development, an example here:



Probability to satisfy the FOM of total efficiency above 0.41, given the degree of power hybridisation and energy hybridisation of the system.

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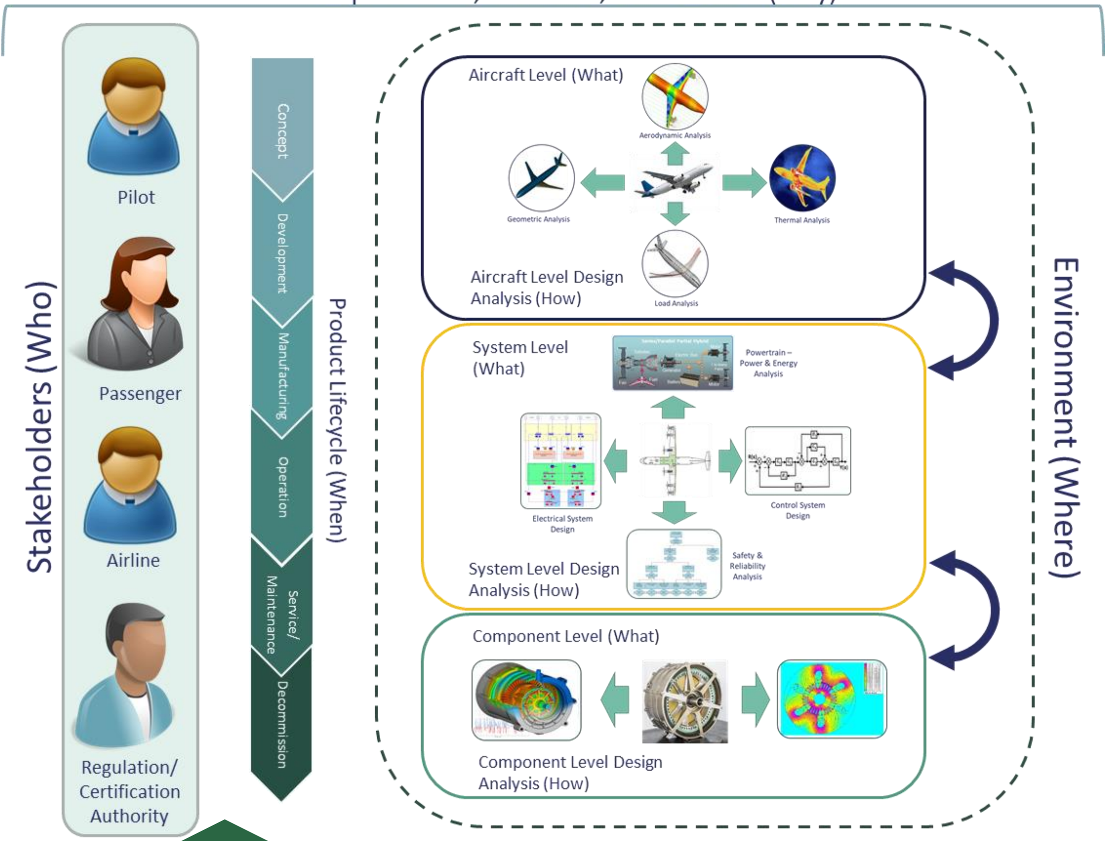
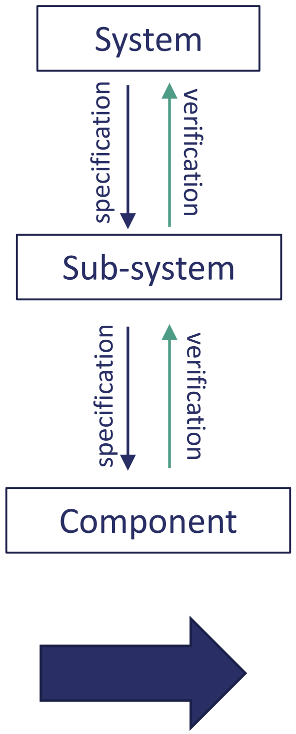
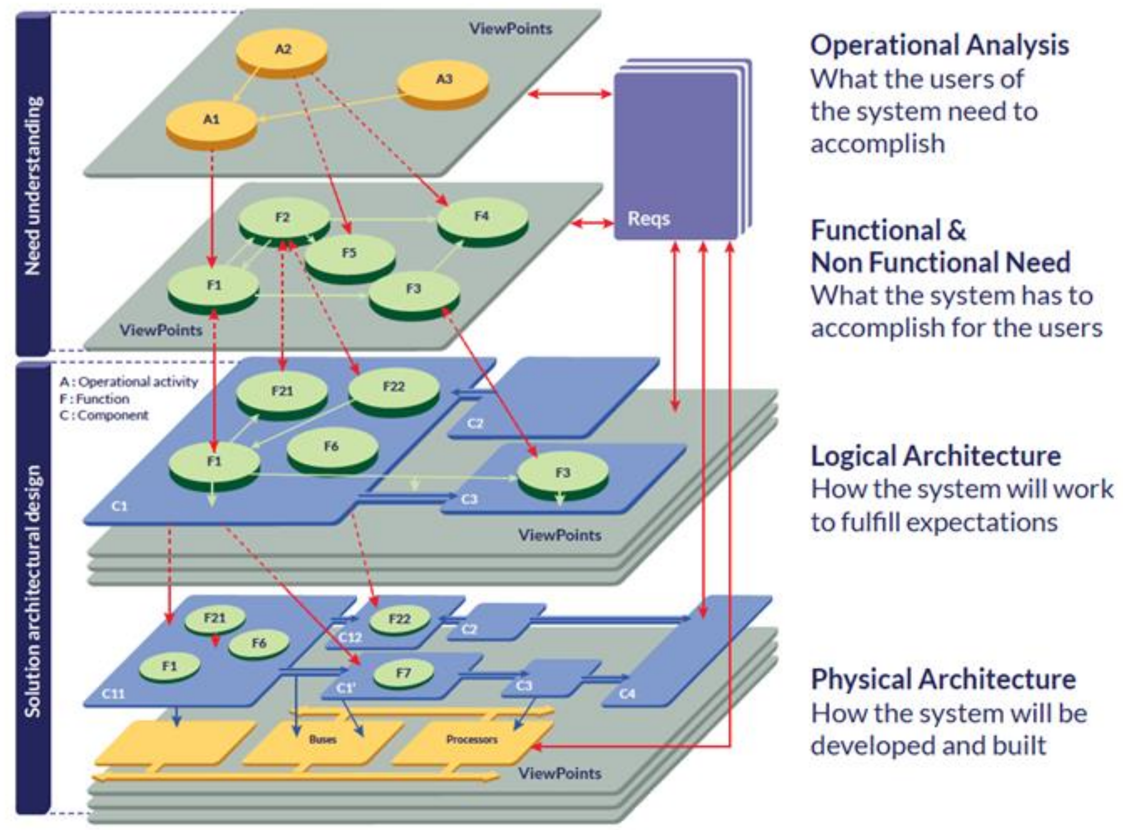
Main Contributions: System Architecture Design – Model Based Systems Engineering (MBSE)

System Engineering Life-Cycle Technical Process – ISO 15288





ARCADIA Methodology (supports ISO 42010)



System Architecture Modelling

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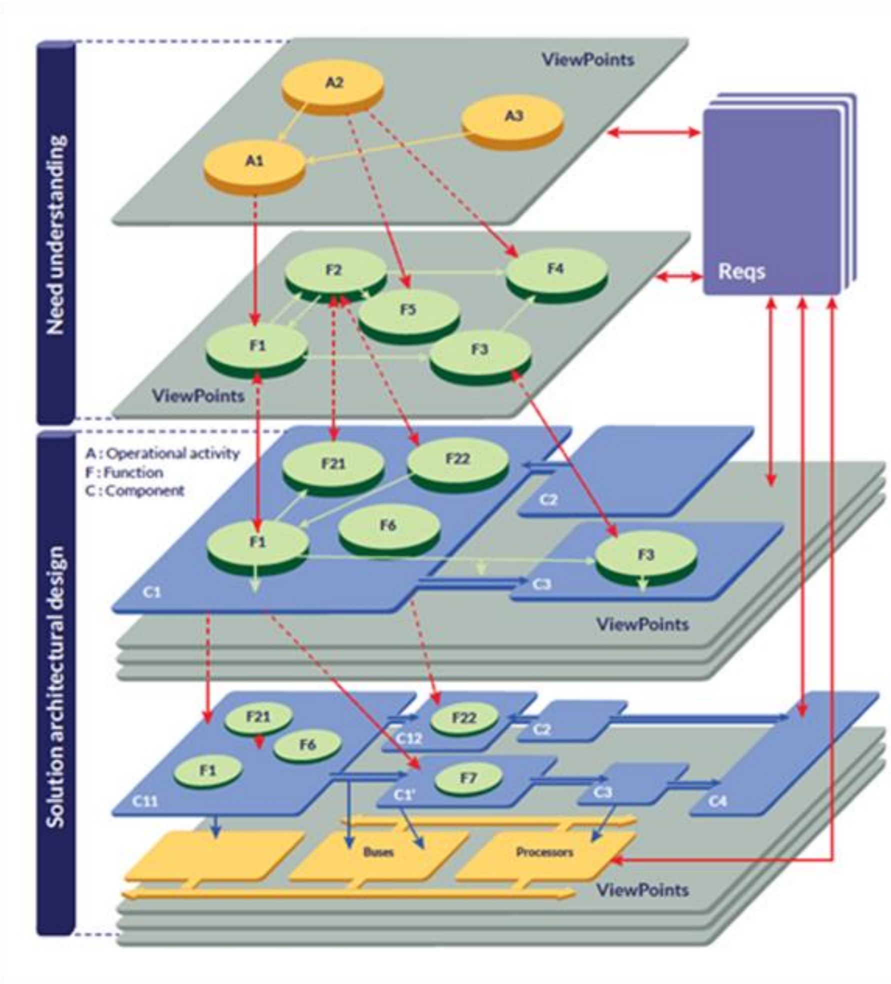
Main Contributions: MBSE Architecture

<u>MBSE Desired Outcomes and Benefits</u>

1. Common domain for mapping of the system & component performance parameters for stakeholders and designers.
2. Defines functional interactions/intra-actions and physical interfaces between subsystems and components for deriving emergent functional behaviour.
3. Improves awareness of component/subsystem/system interaction.
4. Supports trade-off analysis for different architecture designs and component configurations.
5. Provides a means of understanding how design decisions made at a certain system level may impact the characteristics/performance of the system, sub-systems and components.
6. Derive optimisation problems from conflicting functional/ physical parameters of sub-systems/component.



COMPLETE

Operational Analysis
What the users of the system need to accomplish ✓

Functional & Non Functional Need 2.
What the system has to accomplish for the users

Logical Architecture 3.
How the system will work to fulfill expectations

Physical Architecture
How the system will be developed and built 4.

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Main Contributions: MBSE Architecture - Next Steps

<u>MBSE Desired Outcomes and Benefits</u>

1. Common domain for mapping of the system & component performance parameters for stakeholders and designers.
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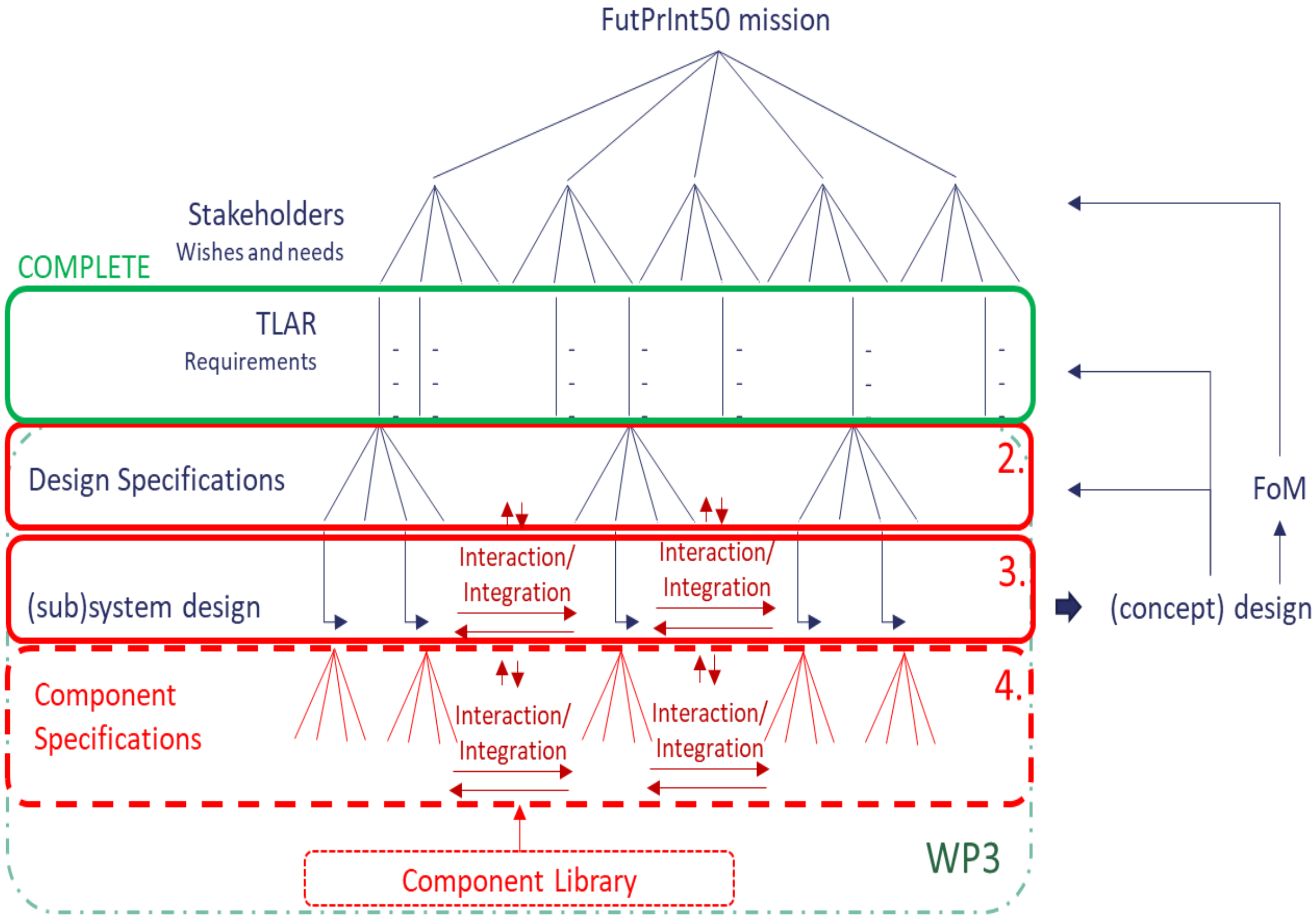

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Main Contributions: Technological Roadmap

2020 — 2040

A **Technology Roadmap** is developed to close the gap between SoA and future requirements for the elements in the hybrid electric power train, such as:

- Energy Harvesting Propellers
- Hybrid-Electric Regional Aircraft
- Battery Technology
- Fuel Cell
- (Liquid) Hydrogen
- Thermal Management & Cryocooling Systems

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Main Contributions: Regulatory Roadmap

A **Regulatory Roadmap** is developed to close the gap between current regulations and future requirements to certify a hybrid electric aircraft, such as:

- Hydrogen
- Emission requirements
- Distributed propulsion
  - Maximum lift
  - Take-off speed
  - Maneuverability
  - Redundancy

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Technical Challenges

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Aircraft Subsystems and Focus of FUTPRINT50

- Aircraft
  - Fuselage
  - Wing
  - Tail
  - Landing Gear
  - Hybrid Electric Powertrain
    - Energy Storage
    - Energy Harvesting
    - Thermal Management
    - …
  - …

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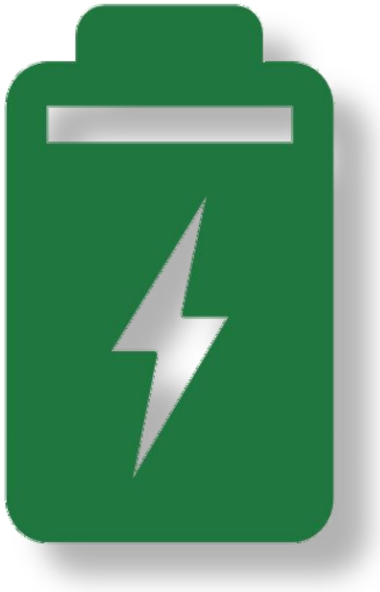
Technical Challenges: Energy Storage

- Optimal sizing between thermal, electrical and mechanical (/safety) aspects
- Safety aspects like thermal runaway
- Specific energy
- Contrast between specific energy and specific power
- Cyclability and lifetime
- Thermal management
- Charging time



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Technical Challenges: Energy Harvesting

- Propeller-wing interaction in the energy-harvesting regime
- Optimizing blade geometry for cruise and/or for harvesting
- Contrast between aerodynamic and aeroacoustic performance
- Effect of enhanced operating envelope on optimal propeller-motor/generator coupling
- Noise in energy-harvesting conditions

Pic credits: Tom Stokkermans

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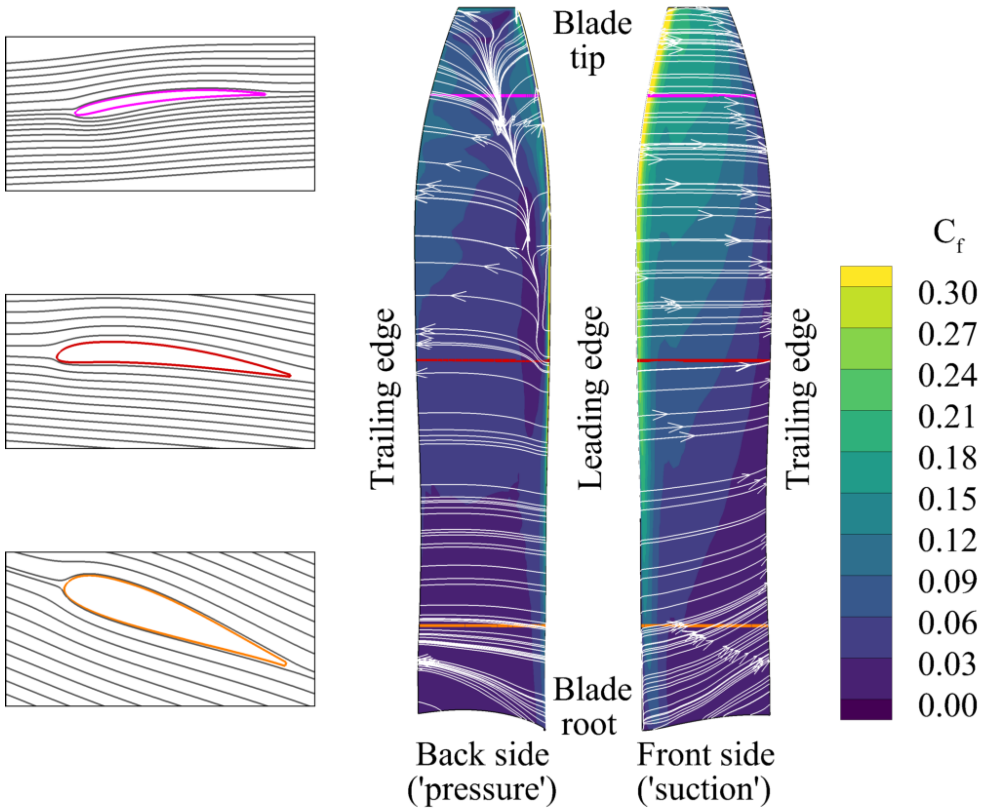
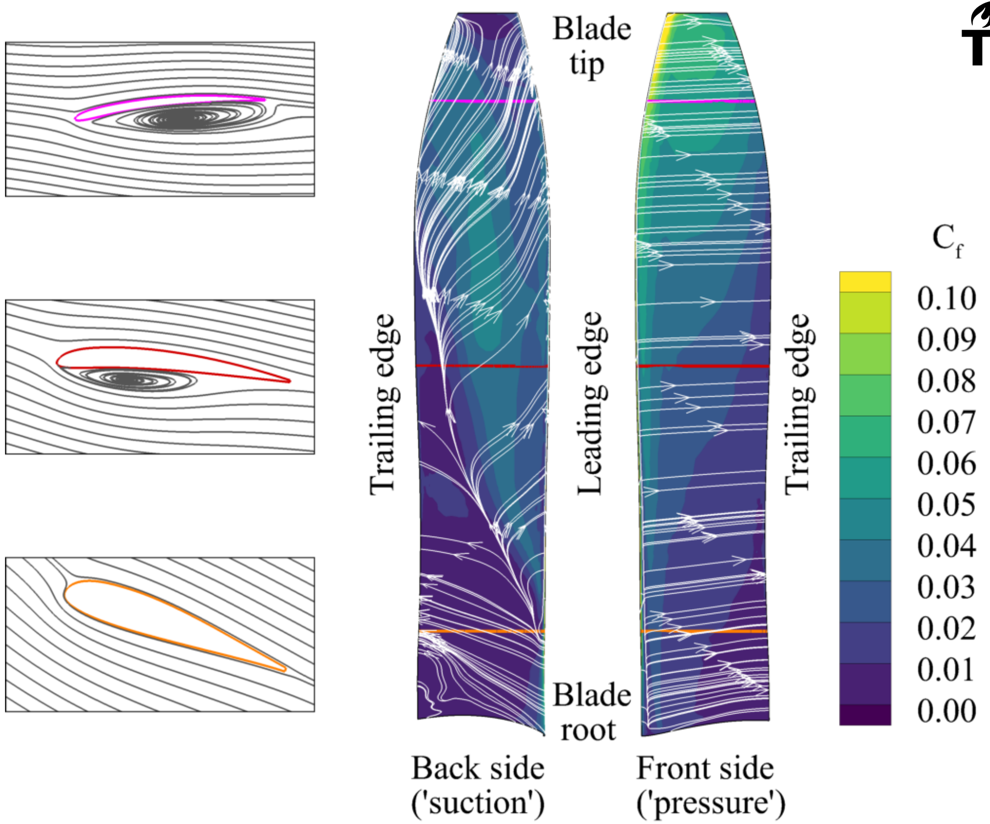
Technical Challenges: Energy Harvesting – Flow around blades in Regeneration (CFD Data)



J = 0.57, $\beta_{0.7R} = 15°$



J = 1.00, $\beta_{0.7R} = 15°$

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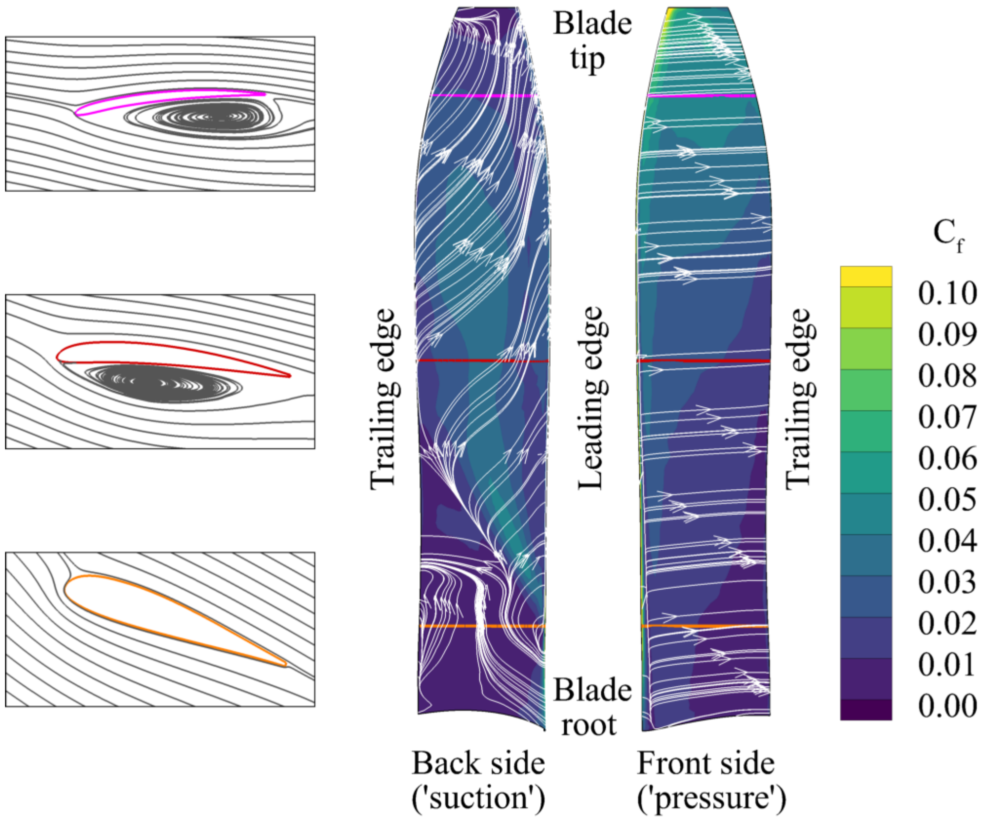
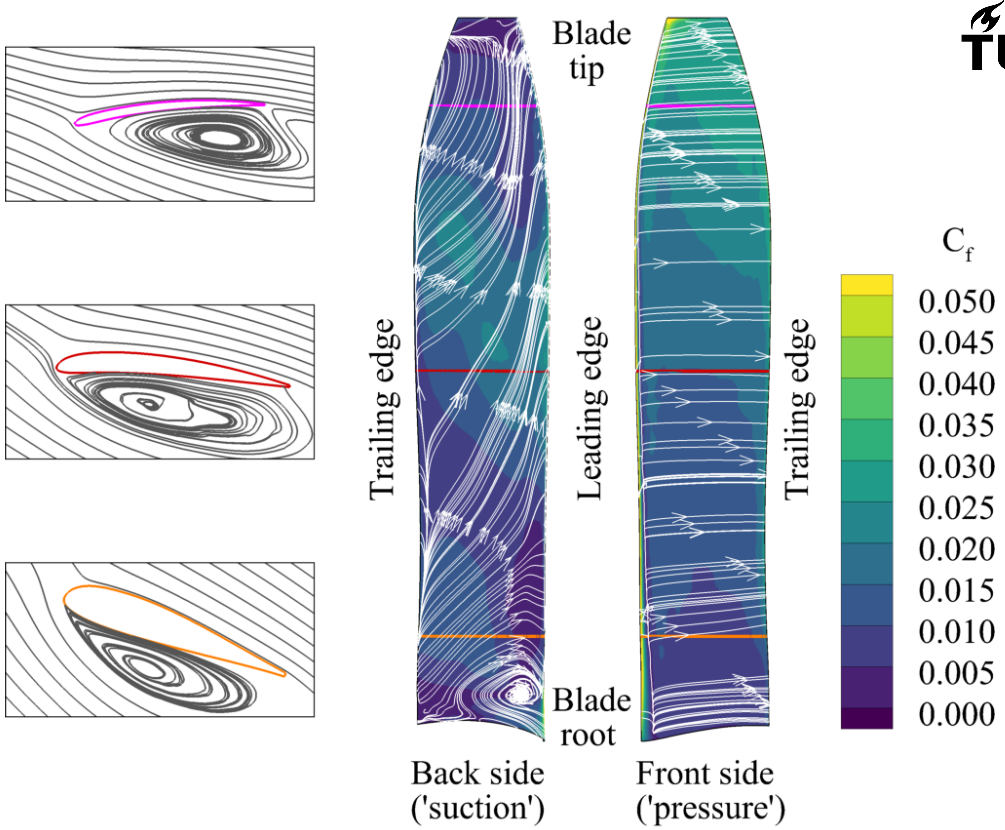
Technical Challenges: Energy Harvesting – Shear lines + Skin Friction Coefficient (CFD Data)

TU Delft



J = 1.15, $\beta_{0.7R} = 15°$



J = 1.60, $\beta_{0.7R} = 15°$

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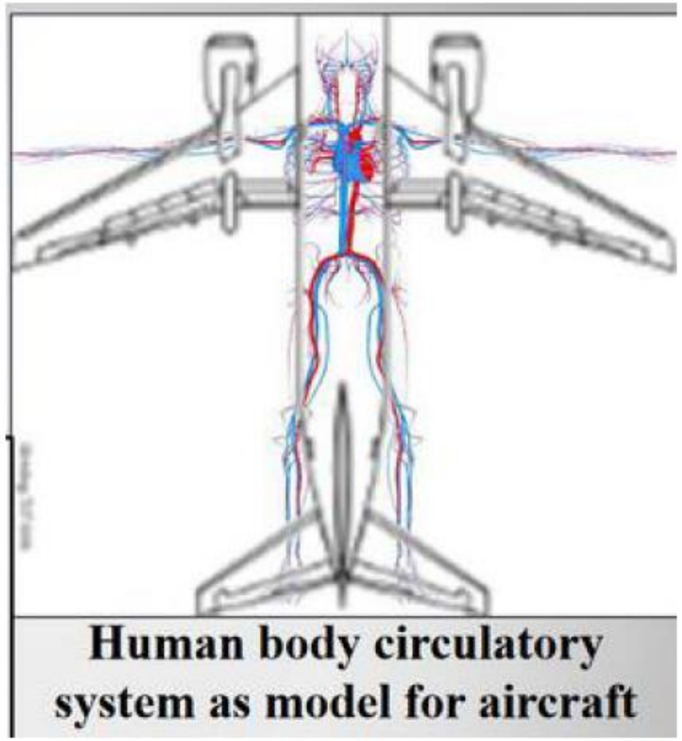
Technical Challenges: Thermal Management System (TMS)

*"Thermal Management is the ability to **manage heat transfer** between heat sources and sinks **to control the temperature of aircraft subsystems/components** in order **to achieve comfort, safety and efficiency**."*



NASA

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Technical Challenges: TMS – architectures and systems for Hybrid Electric Aircraft (HEA)

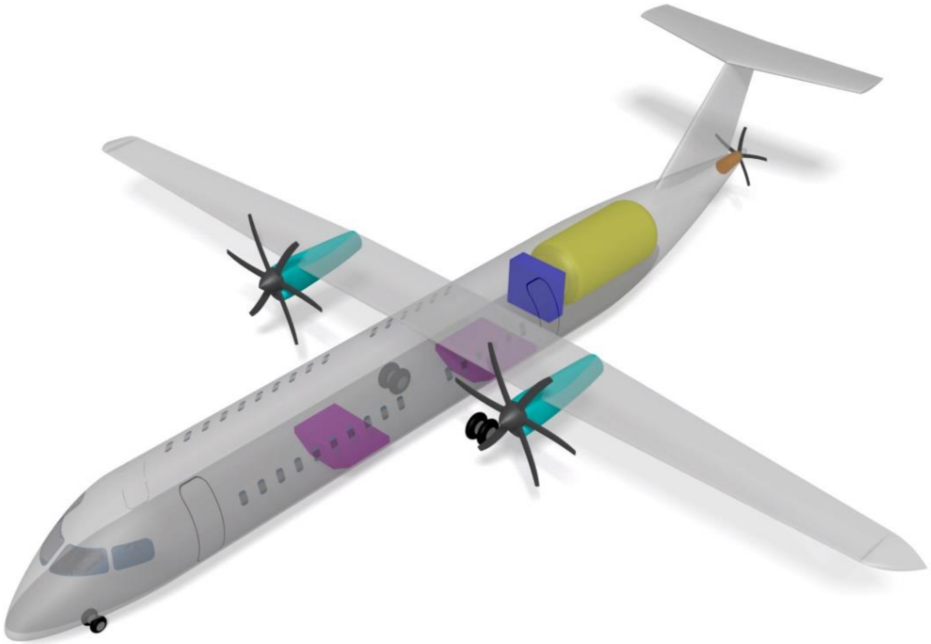
HEAT SOURCES

BATTERY

POWER ELECTRONICS

ELECTRIC MACHINES

OTHERS



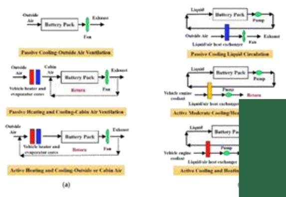
HEAT SINKS

FUEL

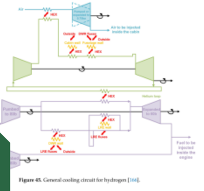
FUSELAGE

RAM AIR

OTHERS



TMS

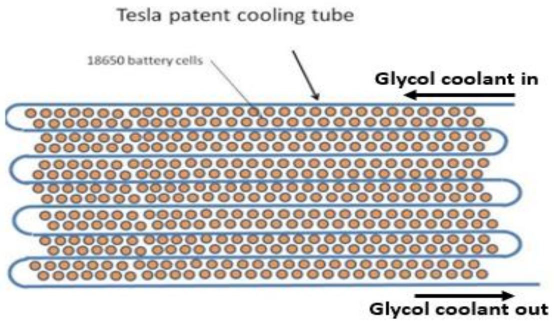


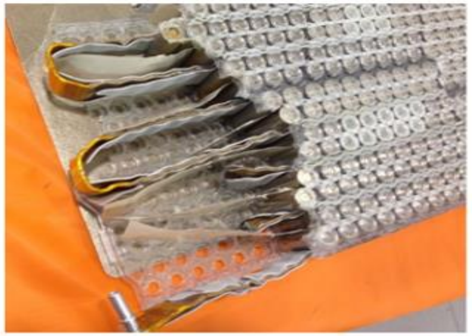
Our goal: advance modelling and simulation for HEA TMS

Technical Challenges: TMS – Overview of technologies for heat transfer

LIQUID COOLING SYSTEMS

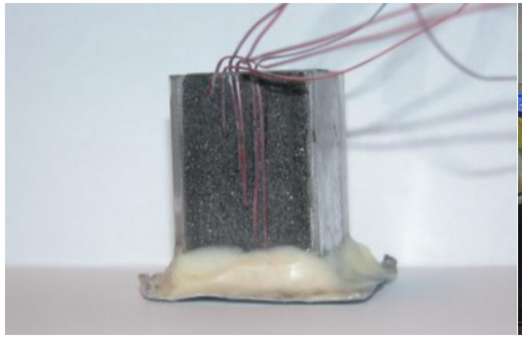
The warm fluid passes through a heat exchanger to be cooled using the ambient as heat sink

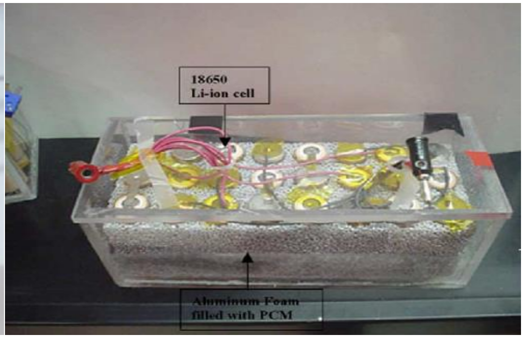




THERMAL ACCUMULATORS (E.G., PHASE CHANGE MATERIALS)

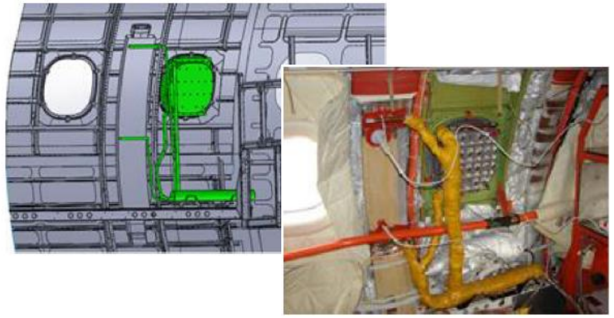
The material reaches its specific phase change temperature

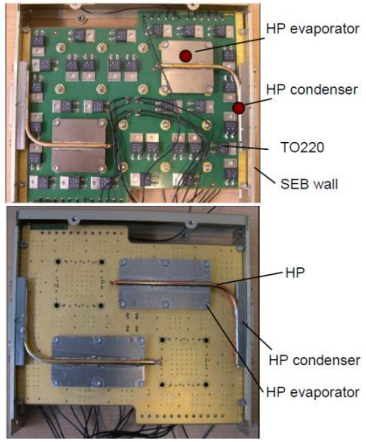




PASSIVE SYSTEMS (E.G., HEAT PIPES, THERMOSYPHONS, VAPOR CHAMBERS)

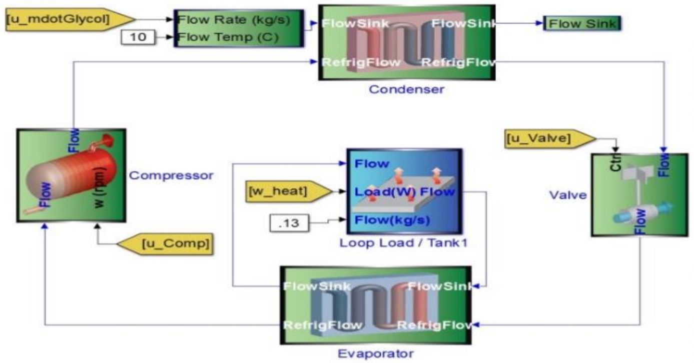
The heat transfer is performed by the evaporation and condensation of the working fluid

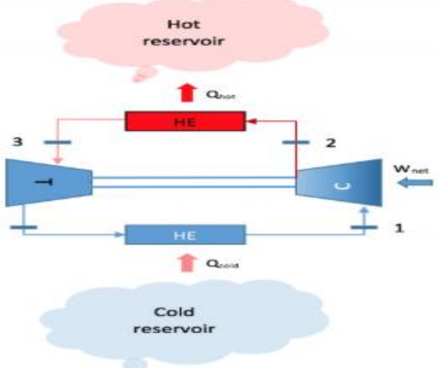




PUMPED TWO PHASE SYSTEMS (E.G., VAPOR CYCLE SYSTEMS, EVAPORATIVE COOLING)

Vapor cycle systems circulate refrigerant fluid via tubing, which absorbs and removes heat from a device and rejects to a heat sink

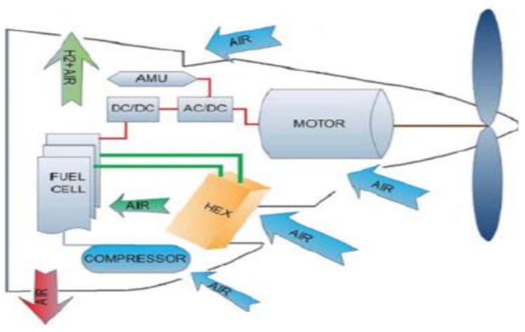


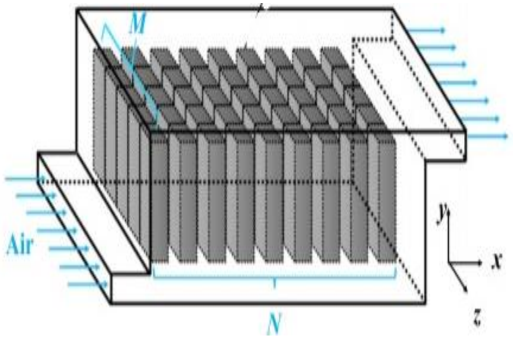


Technical Challenges: TMS – Overview of technologies for heat transfer

AIR COOLING (E.G., FANS, AIR CYCLE MACHINES, RAM AIR)

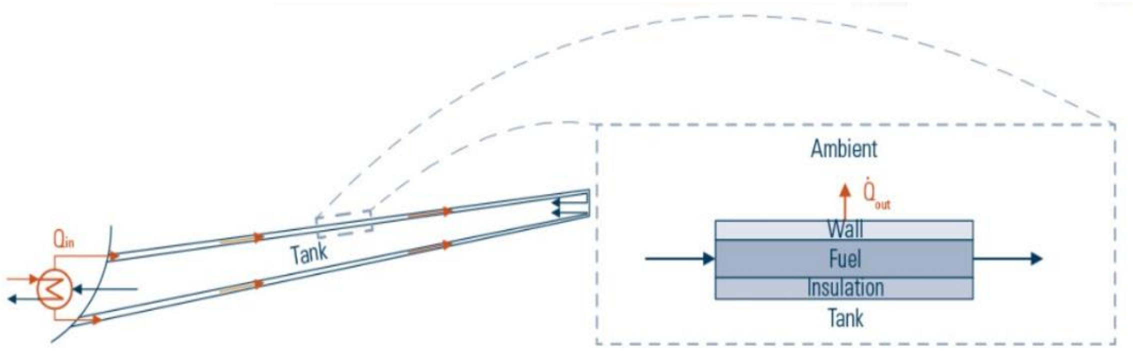
Air cooling is accomplished by flowing air around/inside the heat loads





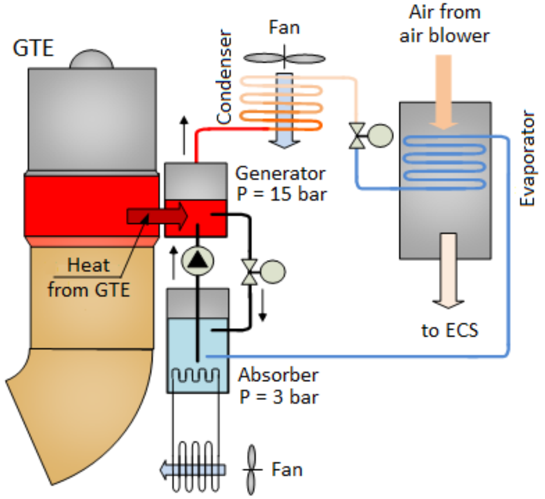
SKIN HEAT EXCHANGERS (E.G., FUSELAGE HEAT EXCHANGERS)

The aircraft skin act as a heat exchanger transferring heat to the ambient air



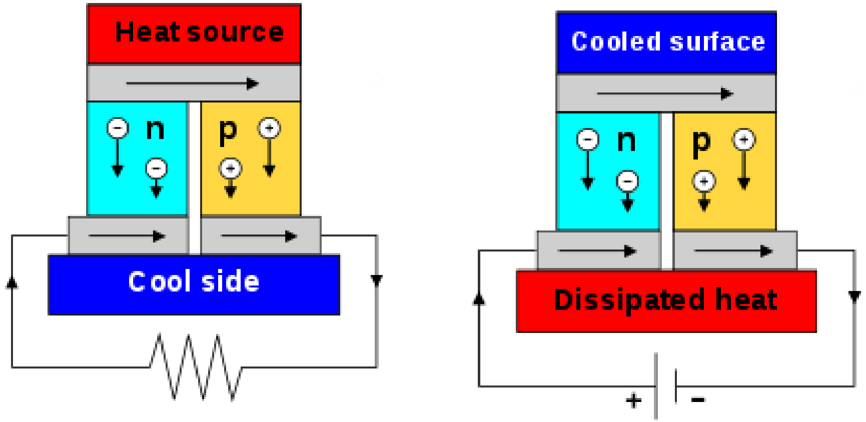
ABSORPTION REFRIGERATOR

Refrigerant is cooled during its absorption by the absorbent



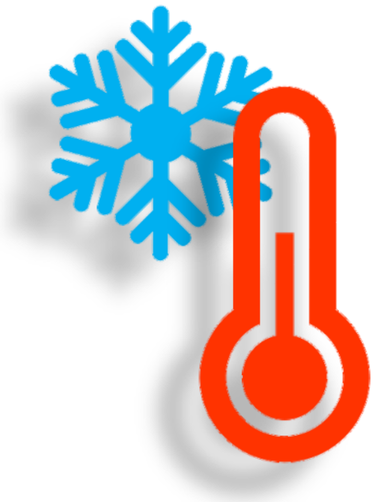
SEEBECK EFFECT AND PELTIER EFFECT

The build up of an electric potential across a temperature gradient and The energy transfer when an electric current passes through the junction of two dissimilar conductors



Technical Challenges: Thermal Management System

- Hydrogen & fuel cells are currently unprecedented and have quite unknown cooling requirements and challenges for this size of aircraft
- High-voltage electrical systems can generate high heat loads not only inside the propulsion equipment but also in the electrical system components, such as power distribution boxes, protection devices, power cables, etc.
- High heat dissipating electrical equipment may be difficult to cool by using common passive systems such as cabin air or ambient (ram) air.
- Operation temperature of most electrical equipment results in smaller ΔT between the component and the cooling fluid and thus makes it harder to be cooled.
- Integrated TMS approaches are important to minimize impacts of the TMS in weight, drag and power consumption at the aircraft level.
- TMS design and optimization strategies include for example thermal energy reuse, energy harvesting, intelligent use of aircraft heat sinks, thermal accumulators/phase change materials, and optimization tools such as MDO and exergy-based analysis.



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Conclusions

Clean Aviation is key for sustainable regional development and resilience!

- EIS 2035/2040 challenging but doable with joint collaboration efforts across the board.
- FUTPRINT50 will develop open reference architectures, models and tools.
- FUTPRINT50 is focusing on energy storage, harvesting and thermal management.
- Learning to scale: complexity, regulations, integration.

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Greening tomorrow's aviation

through disruptive aircraft electrification technologies & international collaboration

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