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Prototypical Control for the Digital Twin of Aircraft Environmental Control System

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TheMa4HERA
Grant Agreement No. 101102008

Imprint

Topic: **Prototypical Control for the Digital Twin of Aircraft Environmental Control System**

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Author: Lepais Corentin

Institute: Institute of System Architectures in Aeronautics (SL) – Air-Vehicle Thermal and Energy Systems

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Digital Twin and virtual demonstration in TheMa4HERA

Hardware test rig

- Test on a single system / a few systems together
- Real conditions but difficult to test all cases
- Real behaviour

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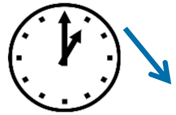
Digital Twin and virtual demonstration in TheMa4HERA

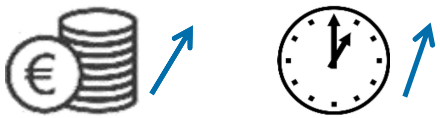
Digital Twin: Virtual test rig



- Possibility to carry out impact assessment at aircraft level
- Tests in multiples conditions and configurations
- Tests of all systems together
- Test possible at an early stage of development
- Results depend on model validity

Digital Twin and virtual demonstration in TheMa4HERA

Hardware test rig



- Test on a single system / a few systems together
- Real conditions but difficult to test all cases
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Digital Twin: Virtual test rig

- Possibility to carry out impact assessment at aircraft level
- Tests in multiples conditions and configurations
- Tests of all systems together
- Test possible at an early stage of development
- Results depend on model validity

Complementarity

- Hardware tests for subsystem model validation
- Digital Twin for overall system demonstration

➔ Demonstration strategy to achieve sysTRL 5

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Digital Twin and virtual demonstration in TheMa4HERA

1. Initial Digital Twin Model

- Interface definition
- Simple and robust models of all systems
- Surrounding models (mission, controllers, environment)

2. Digital Twin Improvement

- Development of high-fidelity models shared as FMU by the partners
- Integration inside the Digital Twin Model

3. Models validation

- Validation of the high-fidelity models by hardware tests
- Validation of the FMU integrations inside the Digital Twin

4. Virtual Demonstration

- Simulation for various environmental and mission conditions
- Outputs for the different performance test cases

Initial Digital Twin Model

1. Initial Digital Twin Model

- Interface definition
- Simple and robust models of all systems
- Surrounding models (mission, controllers, environment)

Modelica

2. Digital Twin Improvement

- Development of high-fidelity models shared as FMU by the partners
- Integration inside the Digital Twin Model

fmi Functional Mock-Up Interface

3. Models validation

- Validation of the high-fidelity models by hardware tests
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DLR ThermoFluid Stream Library

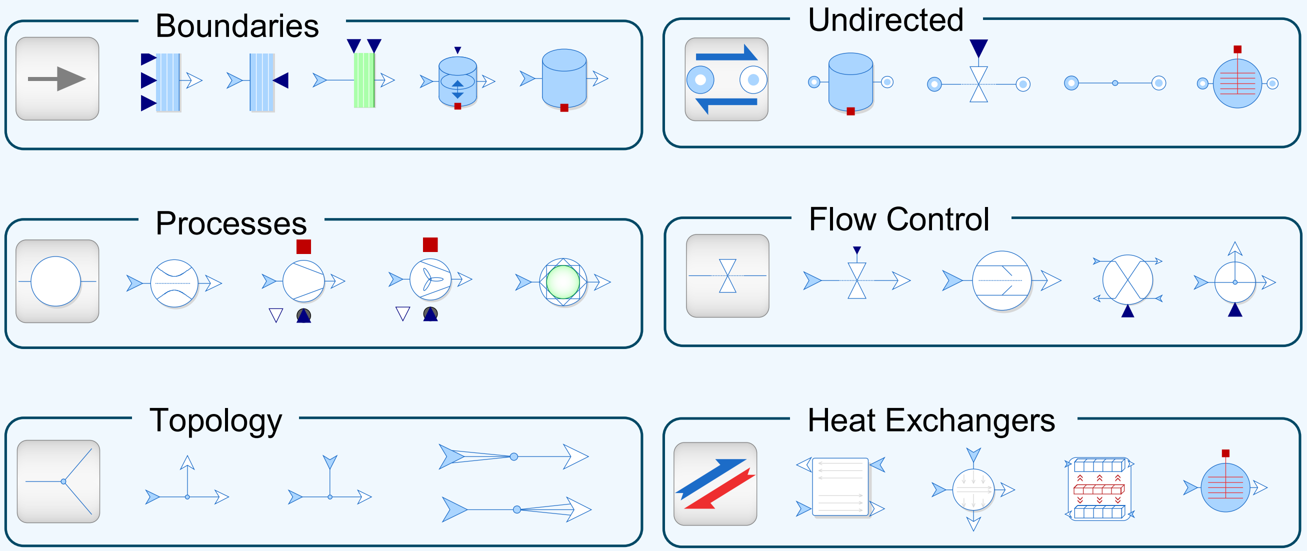
Highlights

Free open-source library
https://github.com/DLR-SR/ThermofluidStream
- Modeling complex thermodynamic systems using gases and/or fluids

Robust
- No larger non-linear equation systems

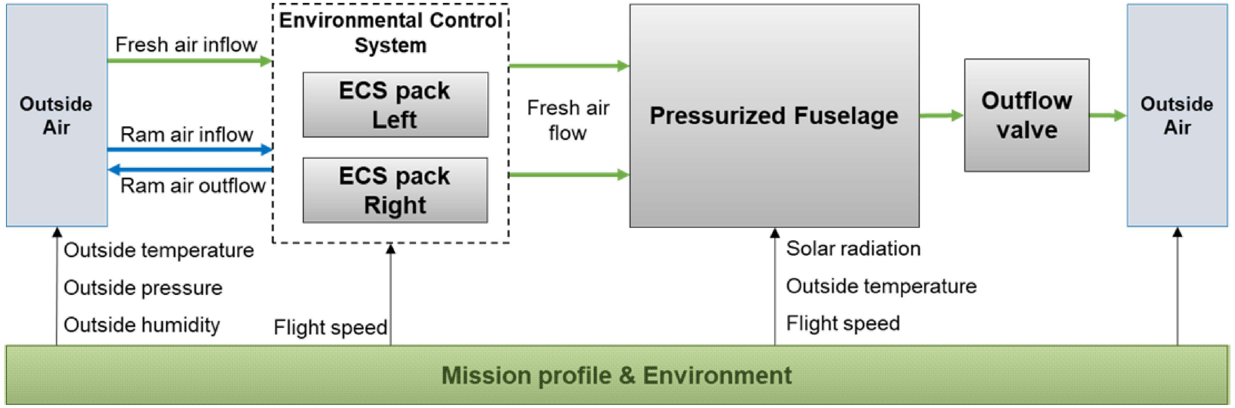
User friendly
- Simple parameterization, easy to initialize
- Many base components easy to adapt
- Many examples to start with

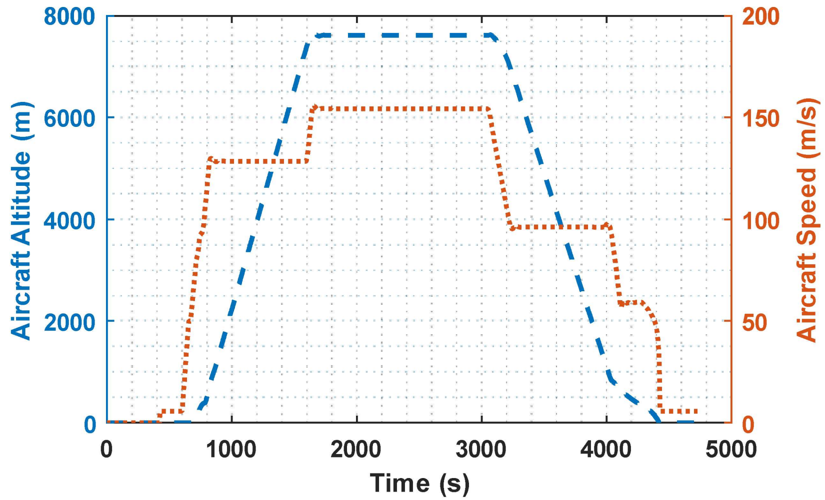
Tool compatible
- Dymola
- OpenModelica

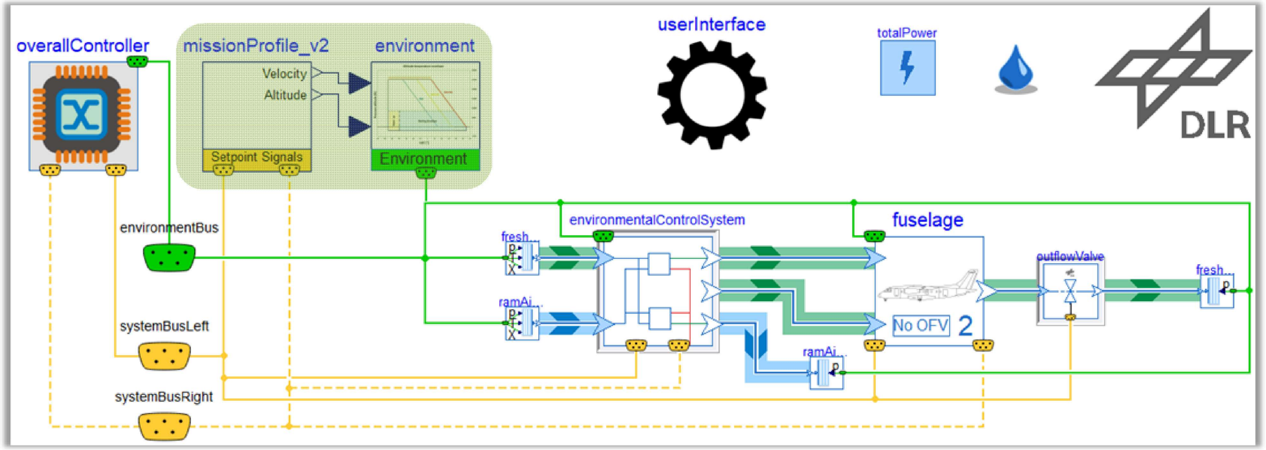


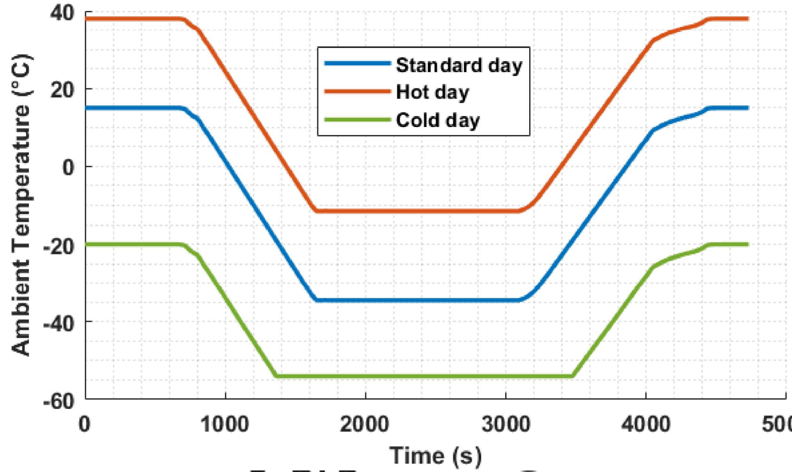
BOEING AIRBUS ABB VATTENFALL VIESSMANN newheat fournisseur de chaleur renouvelable

Environmental Control System Digital Twin

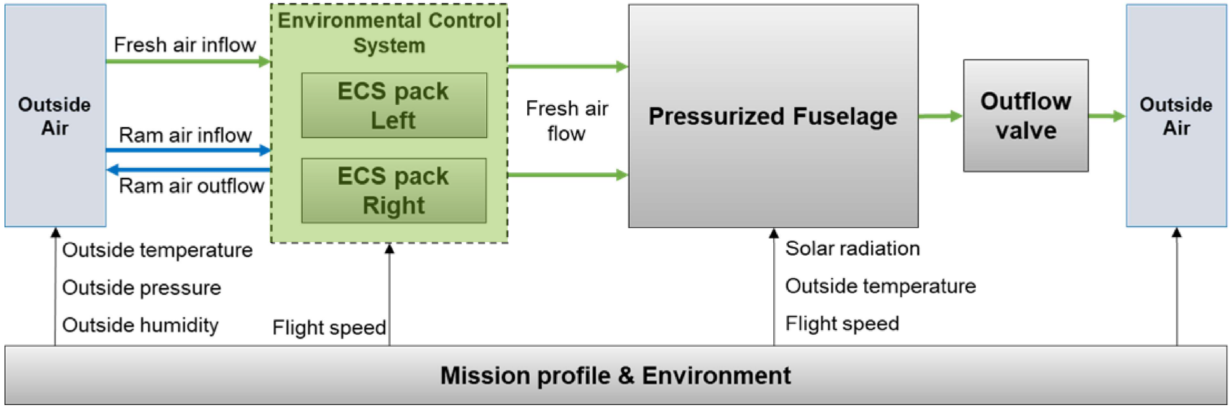


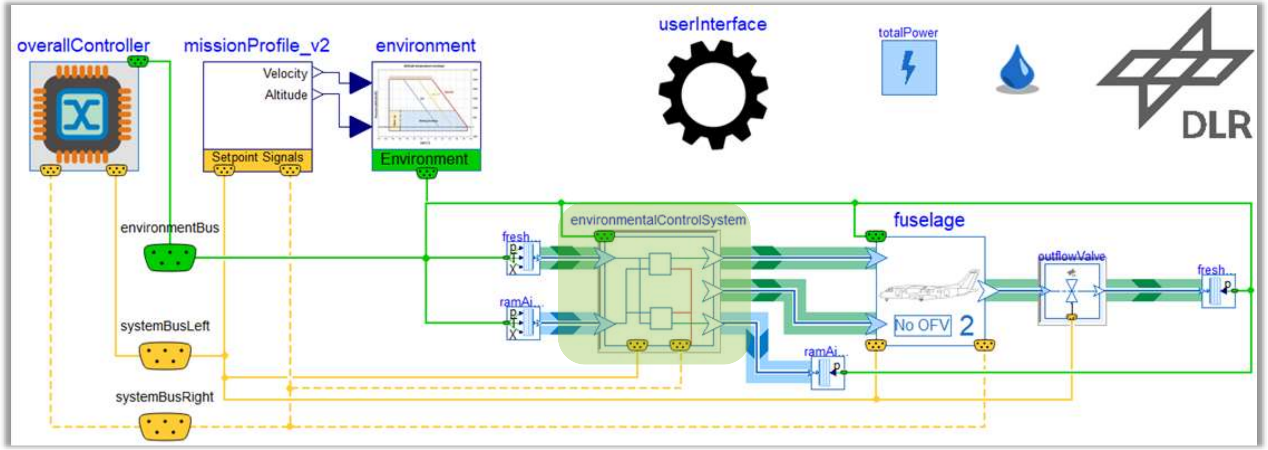


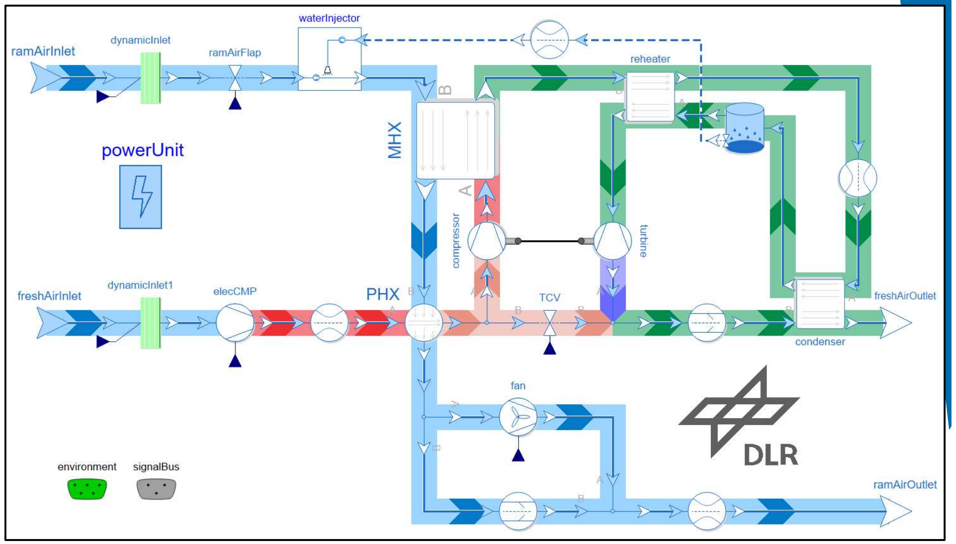




Environmental Control System Digital Twin

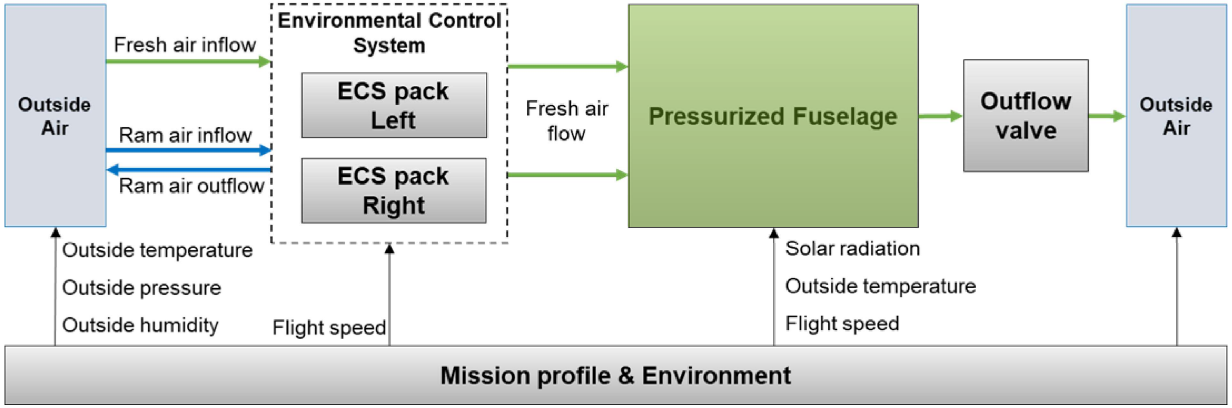


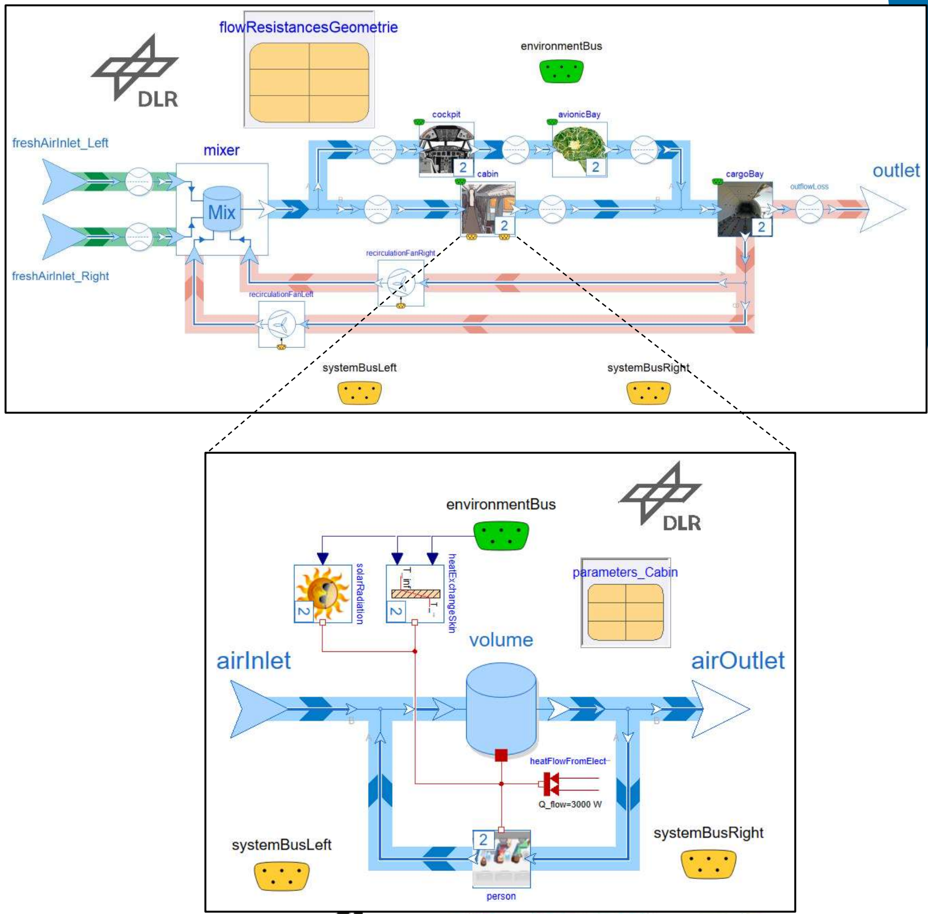


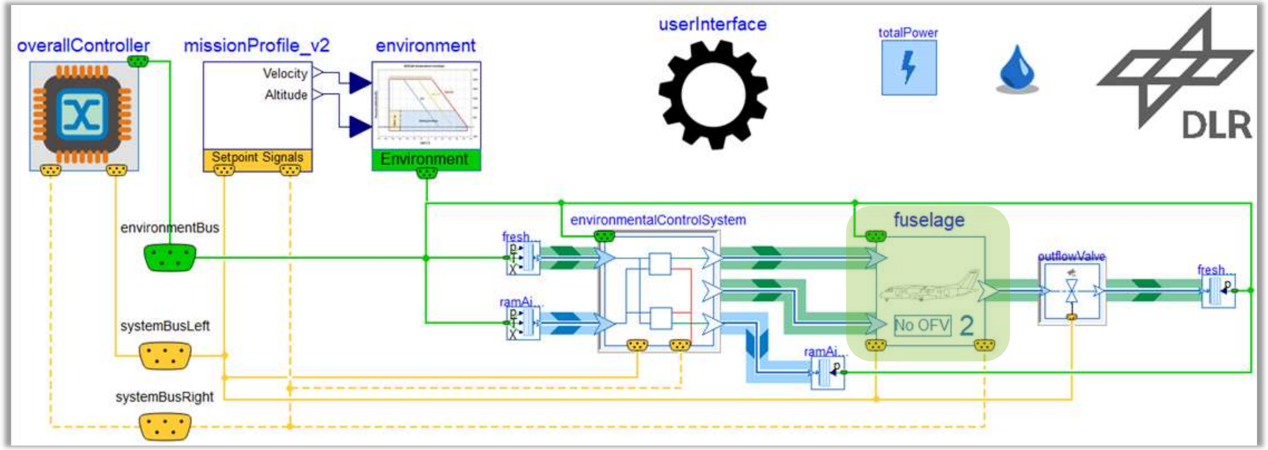


Electrified conventional ECS pack. Bleed air from the engines has been replaced by outside air compressed by an electrical compressor

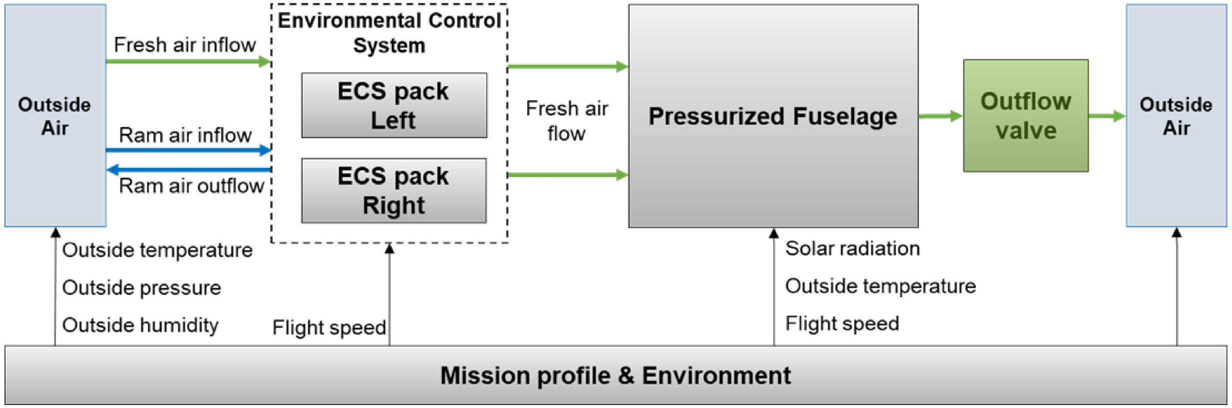
Environmental Control System Digital Twin

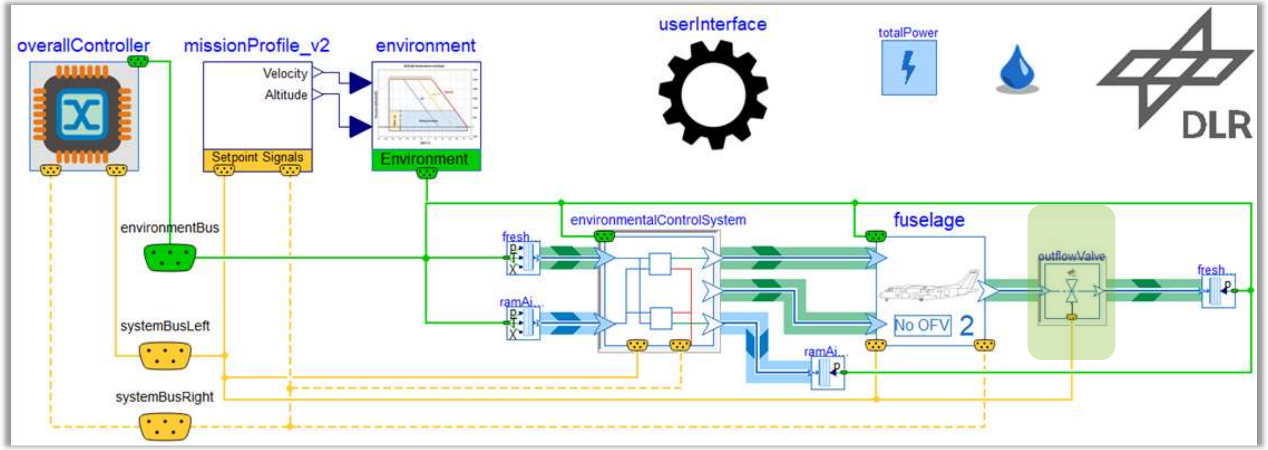


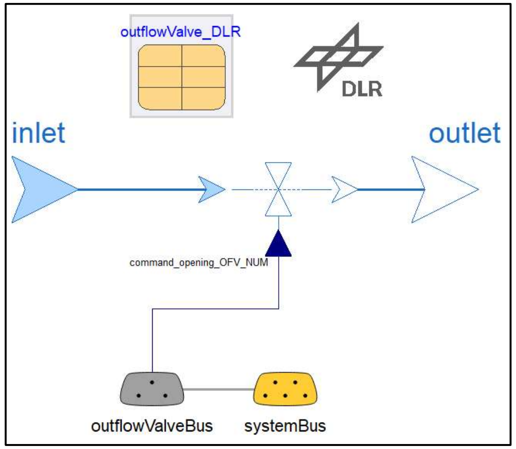




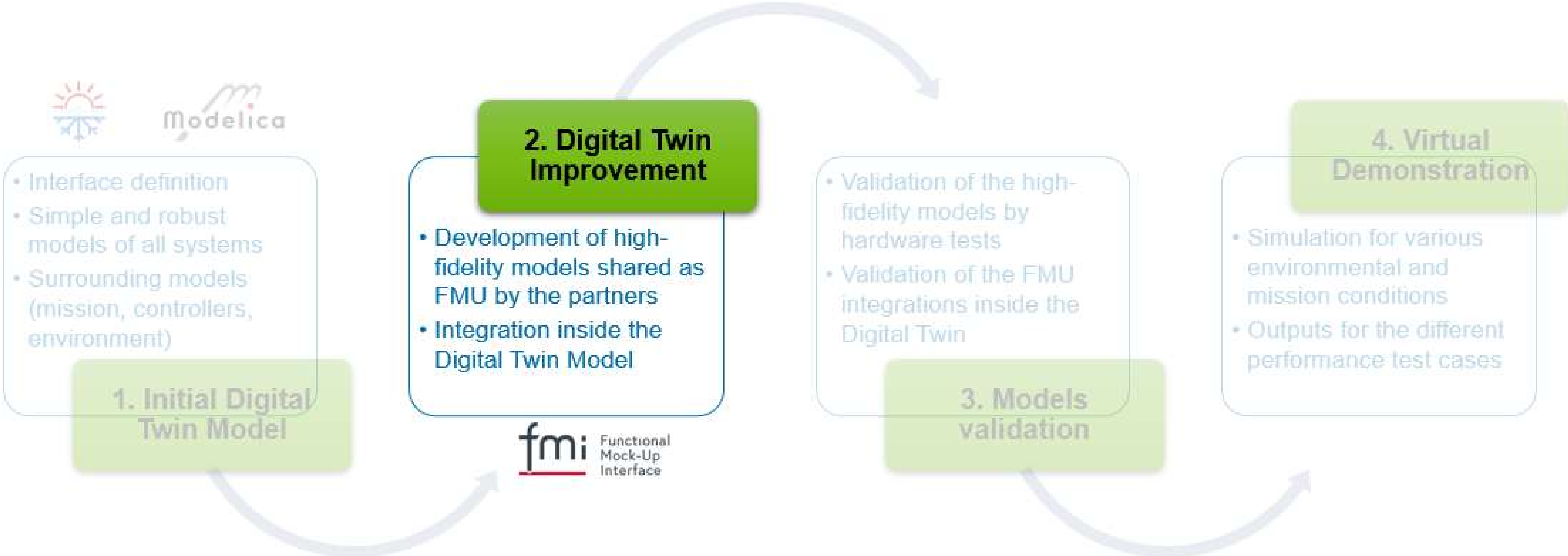
Environmental Control System Digital Twin



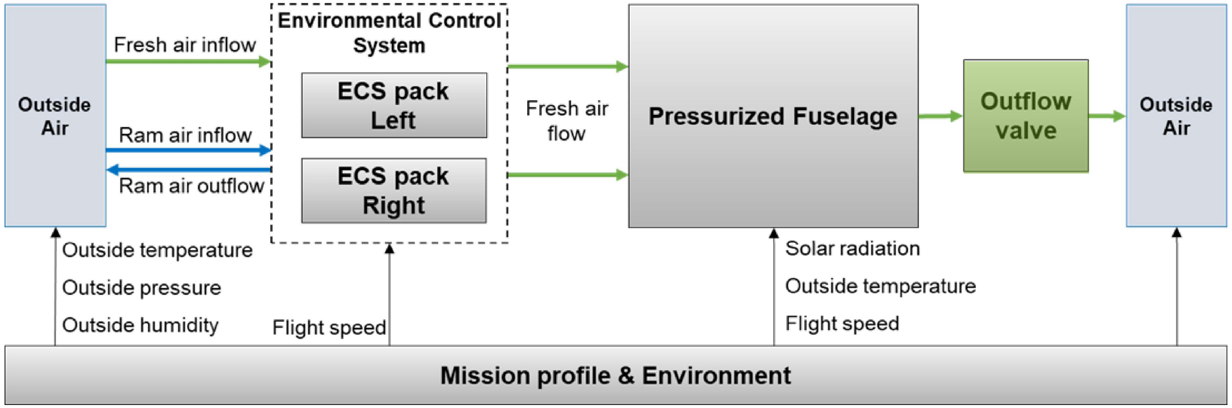


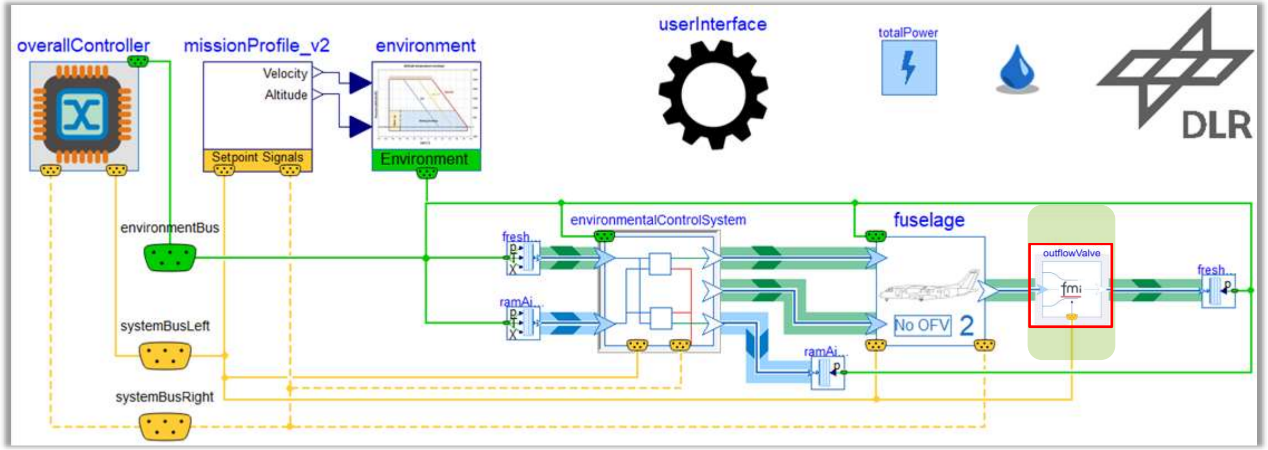


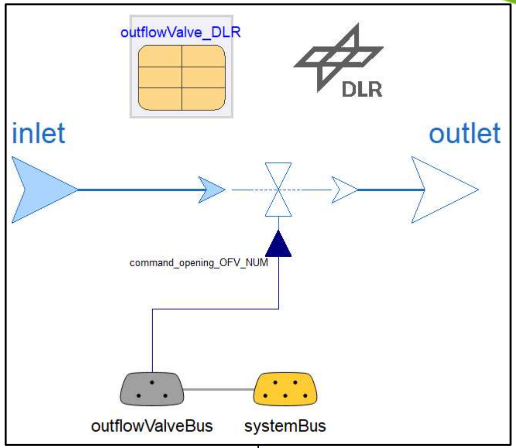
Digital Twin Improvement



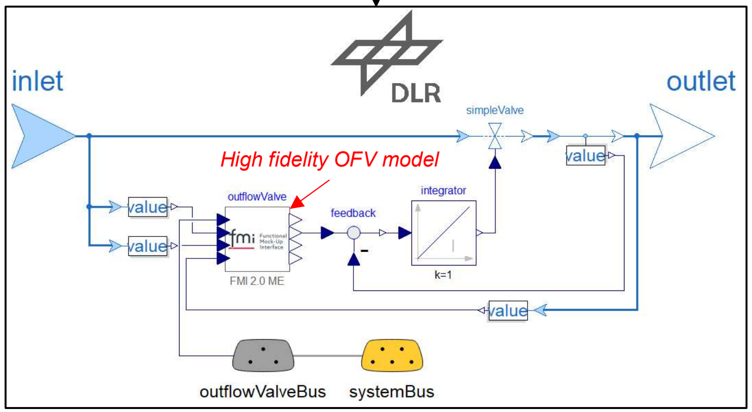
Digital Twin Improvement



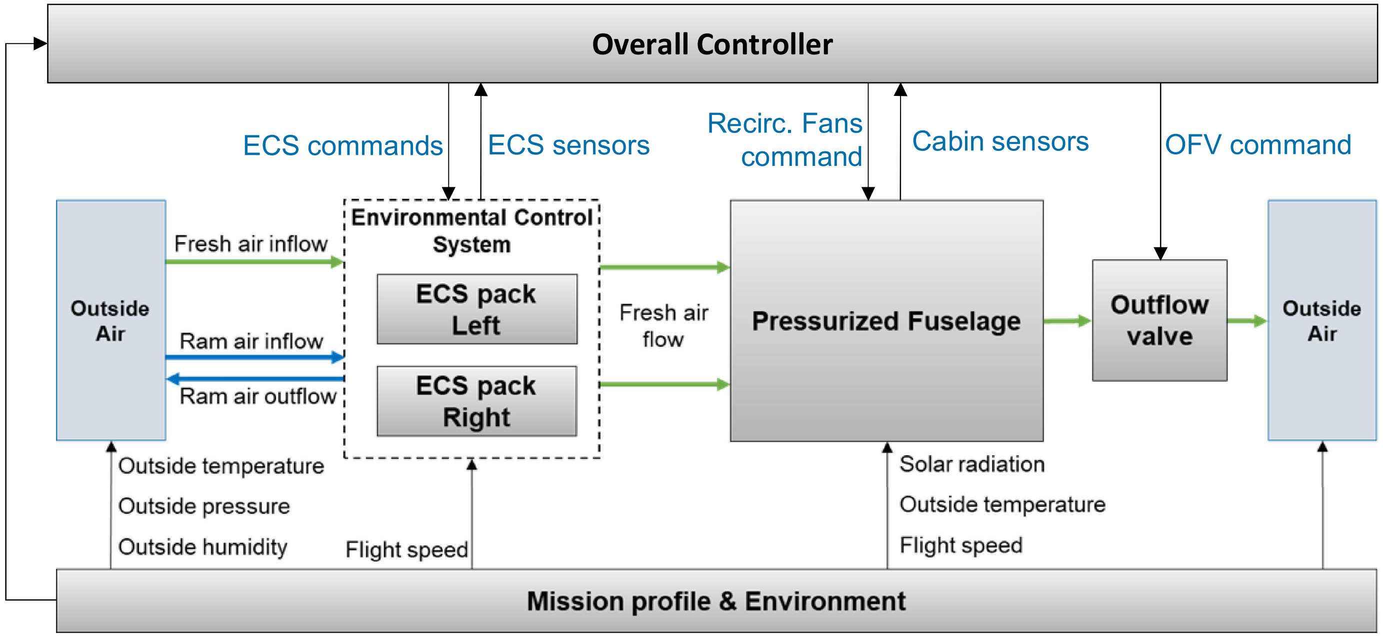




Is replaced by high fidelity model shared as FMU

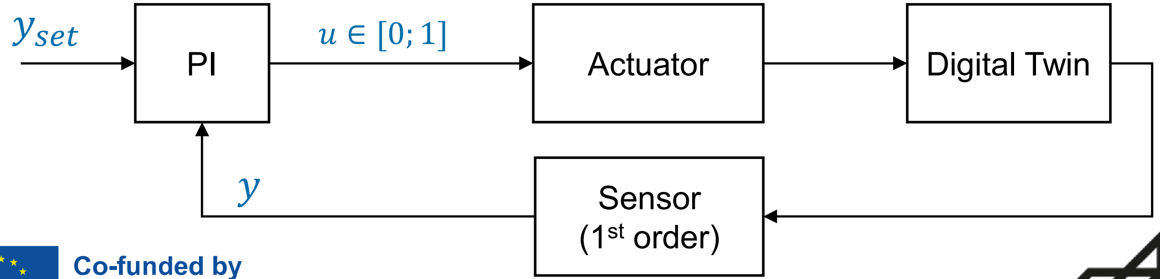


Prototypical Controller Design



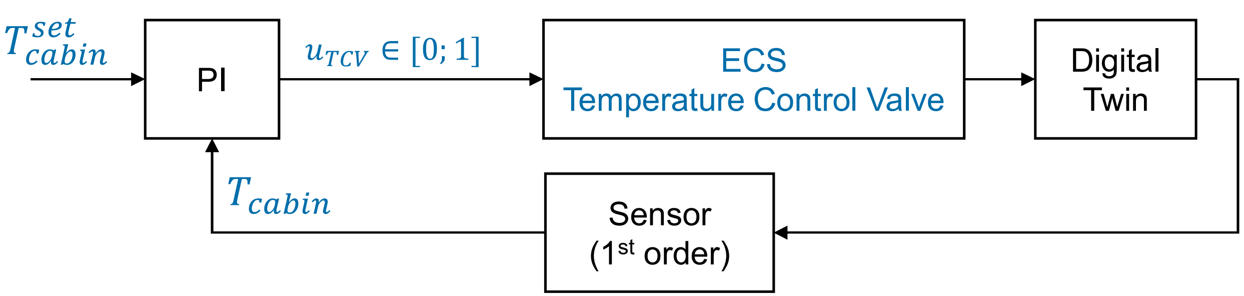
Mission Setpoints
- Cabin Temperature
- Cabin pressure
- Cabin ventilation
- Fresh air supply

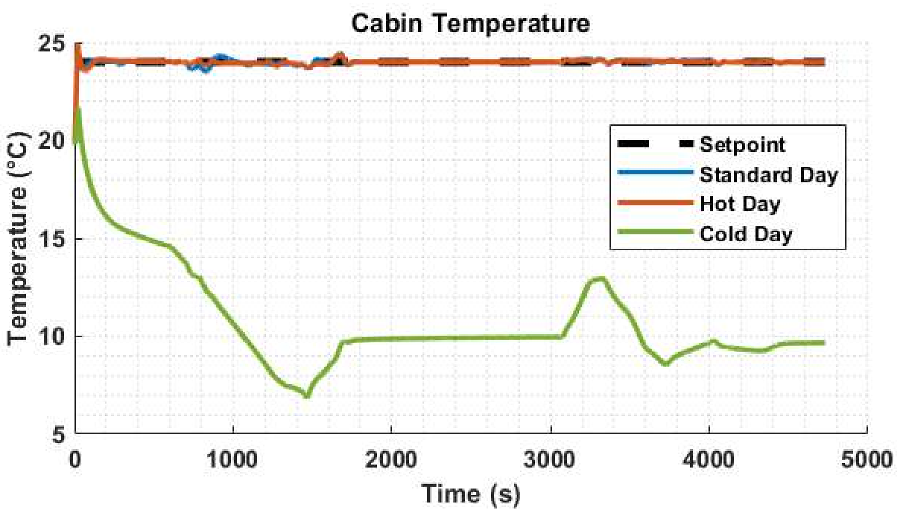
Controller Requirements
- Simplicity
- Adaptability
- Robustness

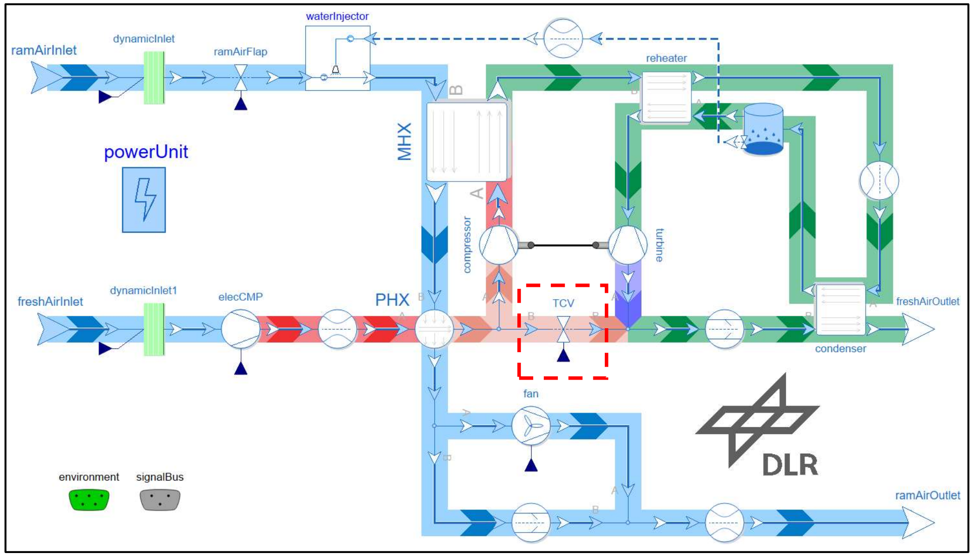


Prototypical Controller Design

Setpoint	Actuator	Command Signal
Cabin Temperature	ECS – TCV	TCV opening

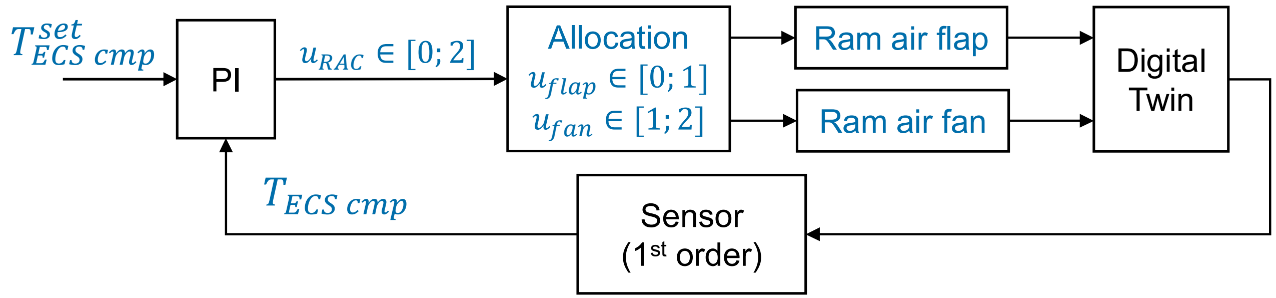


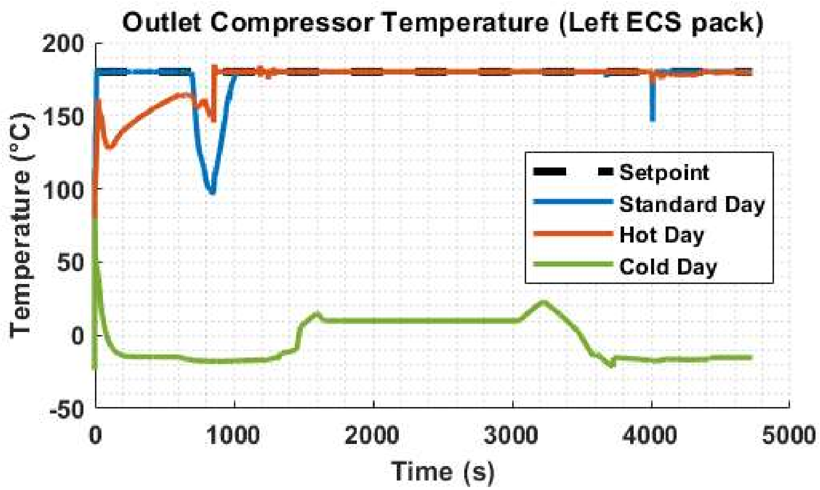


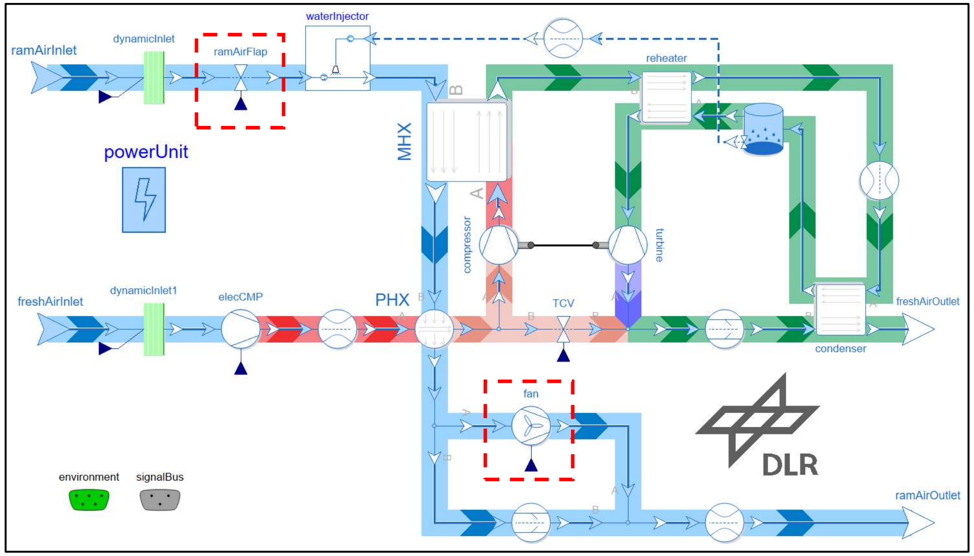


Prototypical Controller Design

Setpoint	Actuator	Command Signal
Cabin Temperature	ECS – TCV	TCV opening
ECS compressor temperature	Ram Air channel	Ram air flap Ram air fan

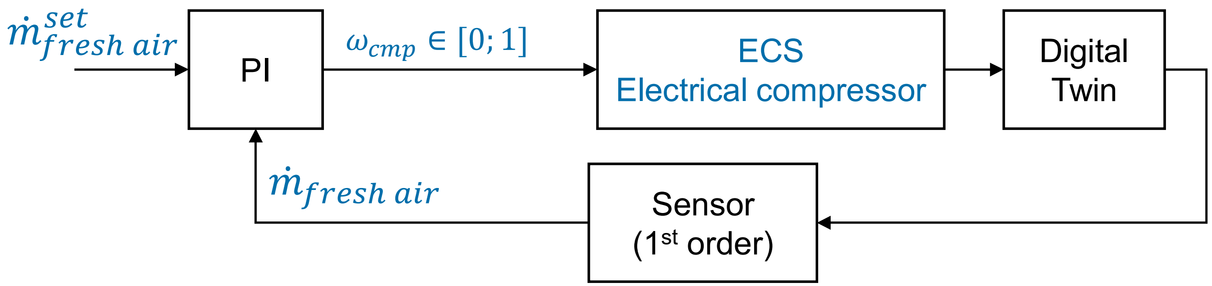


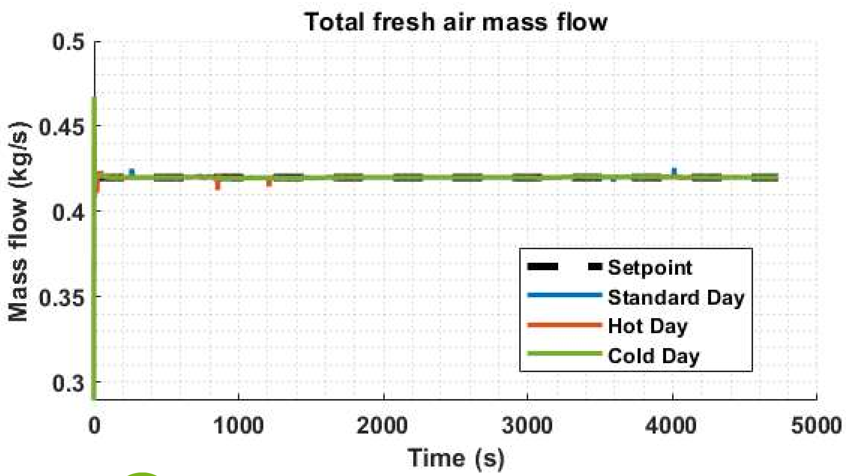


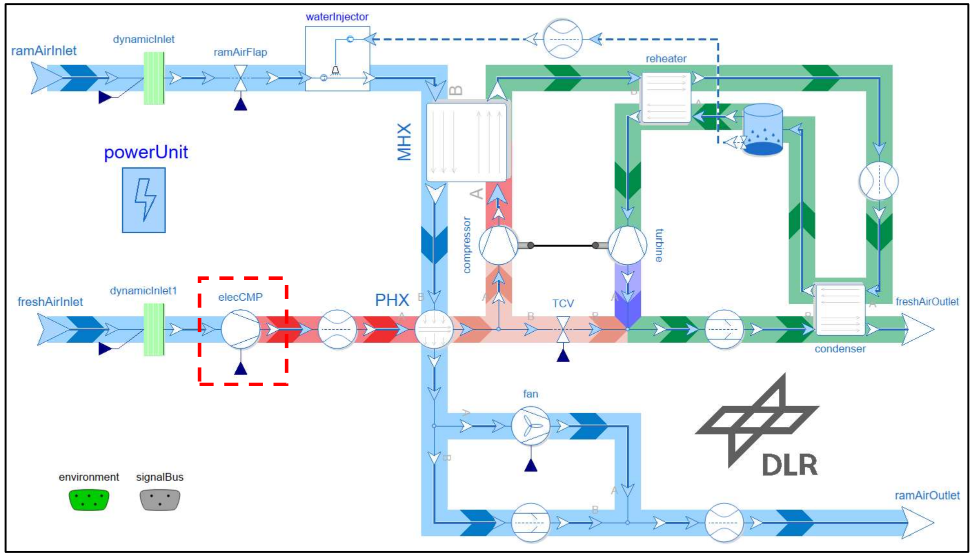


Prototypical Controller Design

Setpoint	Actuator	Command Signal
Cabin Temperature	ECS – TCV	TCV opening
ECS compressor temperature	Ram Air channel	Ram air flap Ram air fan
Fresh air mass flow	ECS – Elec. Compressor	Compressor speed

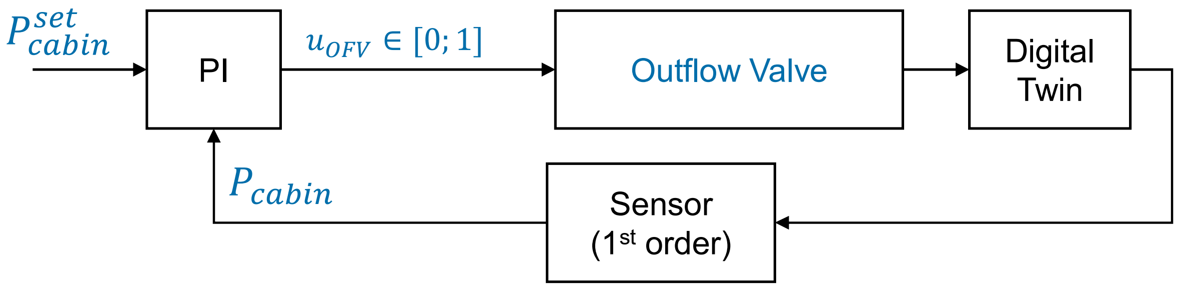


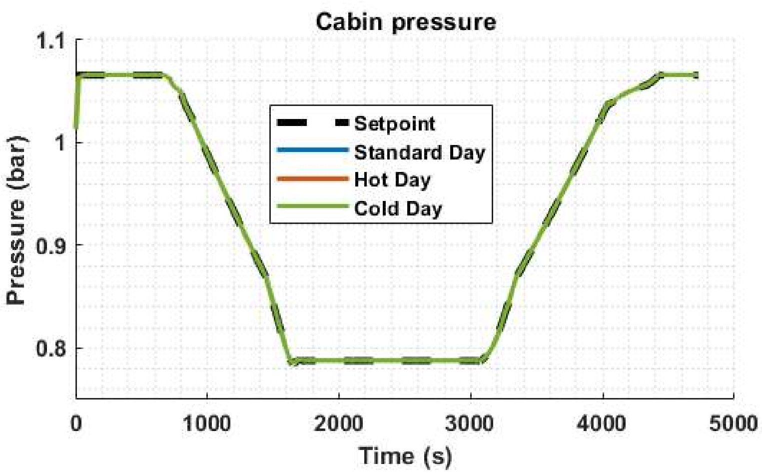


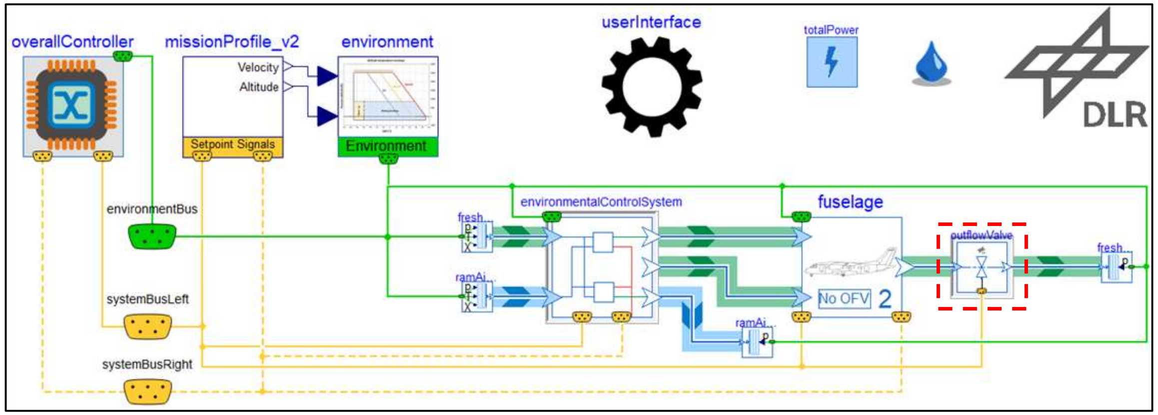


Prototypical Controller Design

Setpoint	Actuator	Command Signal
Cabin Temperature	ECS – TCV	TCV opening
ECS compressor temperature	Ram Air channel	Ram air flap Ram air fan
Fresh air mass flow	ECS – Elec. Compressor	Compressor speed
Cabin Pressure	Outflow valve	Outflow valve opening

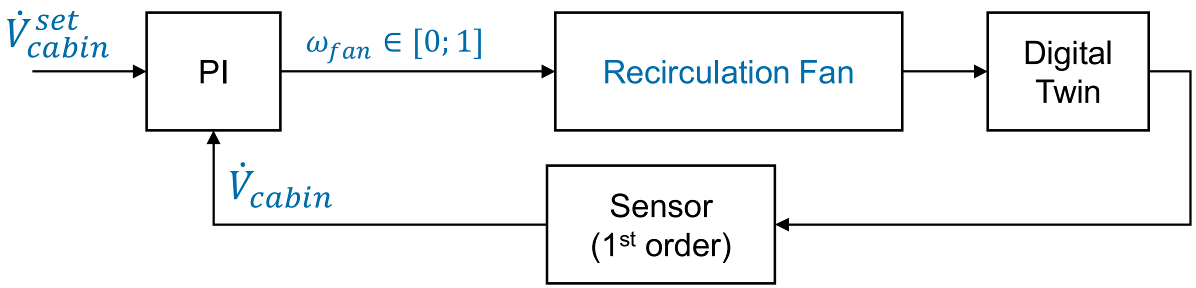


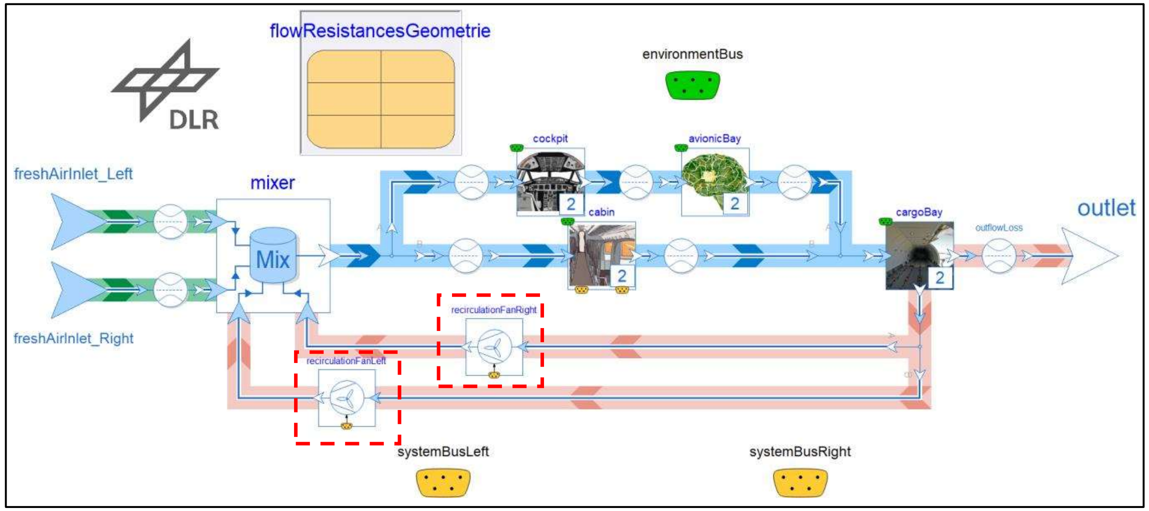


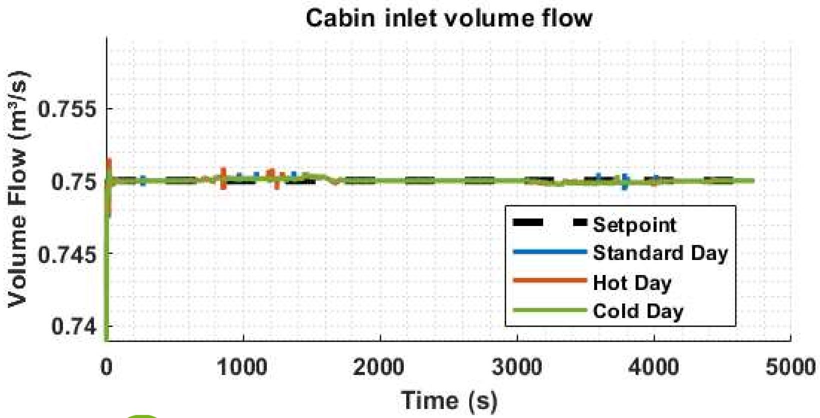


Prototypical Controller Design

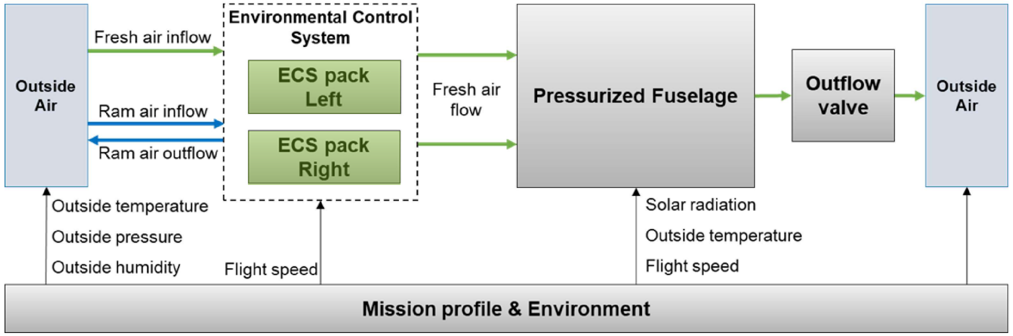
Setpoint	Actuator	Command Signal
Cabin Temperature	ECS – TCV	TCV opening
ECS compressor temperature	Ram Air channel	Ram air flap Ram air fan
Fresh air mass flow	ECS – Elec. Compressor	Compressor speed
Cabin Pressure	Outflow valve	Outflow valve opening
Cabin inlet volume flow	Recirculation Fan	Fan speed



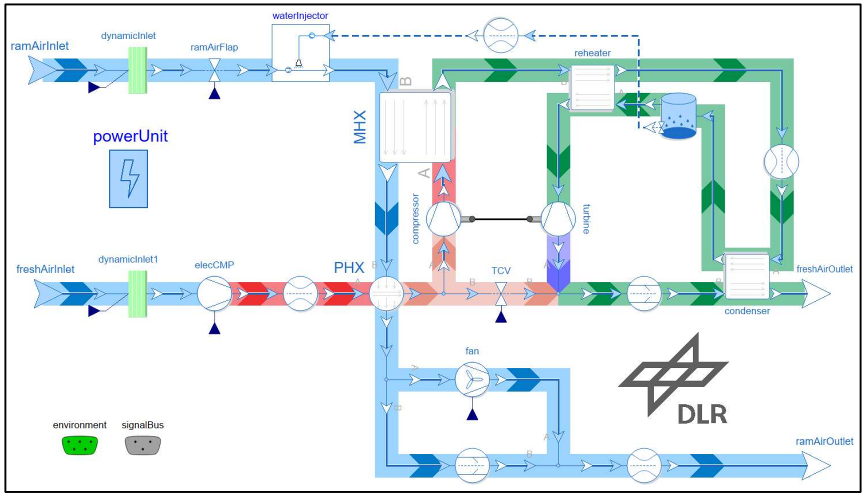




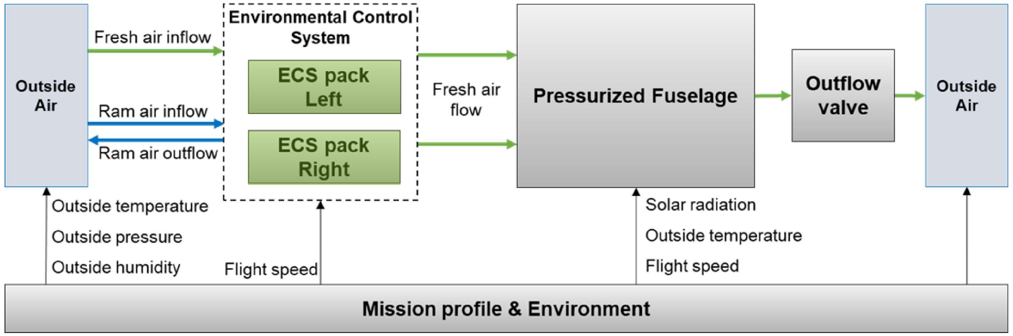
Prototypical Controller Robustness



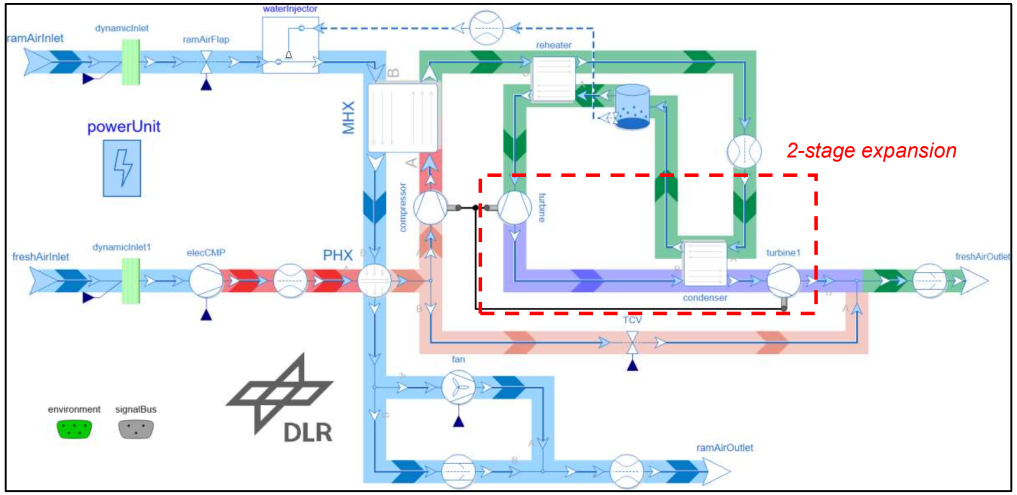
Initial ECS pack architecture



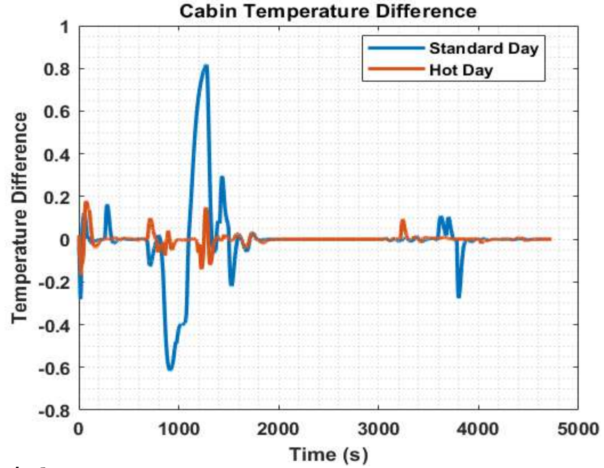
Prototypical Controller Robustness



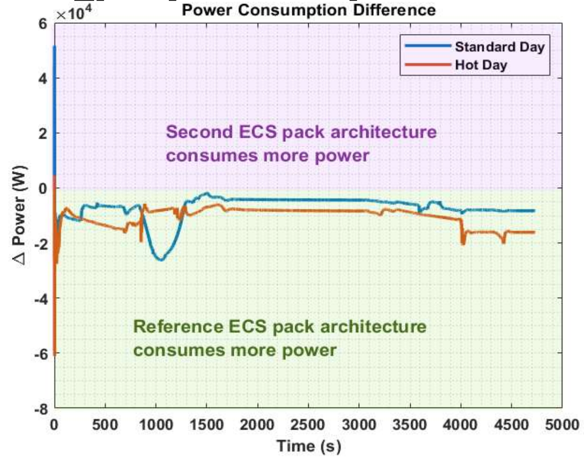
New ECS pack architecture



$$\Delta T = T_{cabin}^{new\ ECS} - T_{cabin}^{initial\ ECS}$$



$$\Delta P = P^{new\ ECS} - P^{initial\ ECS}$$



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Outlook

✓ Complete model of an aircraft environment control system based on simple models
✓ Working prototypical control for complete gate-to-gate mission and various ambient conditions

1. Initial Digital Twin Model

- Interface definition
- Simple and robust models of all systems
- Surrounding models (mission, controllers, environment)

2. Digital Twin Improvement

- Development of high-fidelity models shared as FMU by the partners
- Integration inside the Digital Twin Model

✓ Prototypical control still working when used with a different ECS pack
→ Test to be done now with an high-fidelity FMU models

3. Models validation

- Validation of the high-fidelity models by hardware tests
- Validation of the FMU integrations inside the Digital Twin

→ Once all simple models are replaced by high-fidelity ones, validation of the model integrations can be performed and then the complete system can be virtually demonstrated

4. Virtual Demonstration

- Simulation for various environmental and mission conditions
- Outputs for the different performance test cases

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Conclusion

- Complete initial Digital Twin of an Environmental Control System for hybrid electric aircraft based on simple models
- Prototypical controller design to allow simulation on gate-to-gate mission with desired temperature and pressure inside the cabin
- Prototypical controller robustly designed to make it compatible with high-fidelity models

Contact

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SCAN ME

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Acknowledgements

The project is supported by the Clean Aviation Joint Undertaking and its members.

Clean Aviation is the EU's leading research and innovation program for transforming aviation towards a sustainable and climate neutral future. As a European public-private partnership, Clean Aviation pushes aeronautical science beyond the limits of imagination by creating new technologies that will significantly reduce aviation's impact on the planet, enabling future generations to enjoy the social and economic benefits of air travel far into the future.
Visit the website to find out more about Clean Aviation: www.clean-aviation.eu

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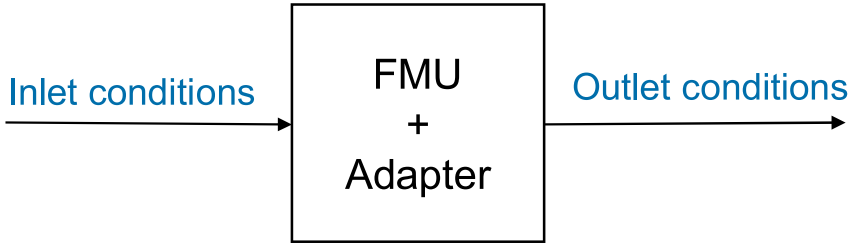
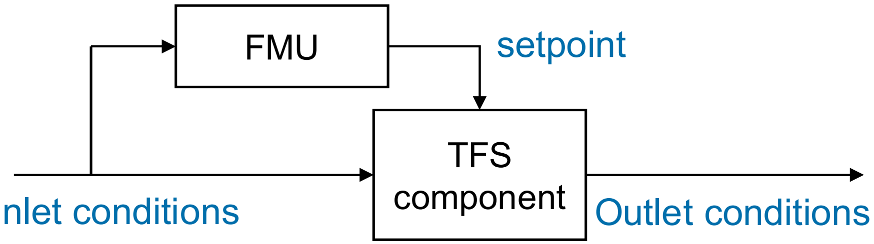
Digital Twin Improvement - Integration of FMU

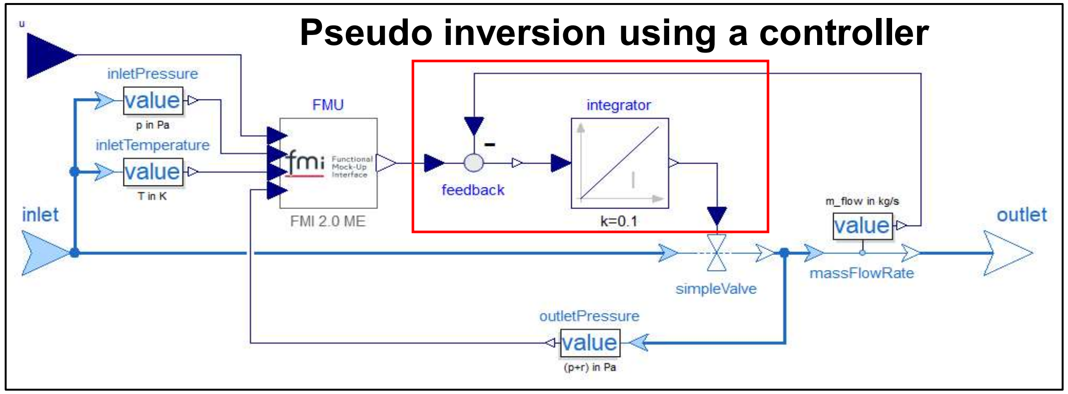
Modelica Standard Library approach



Control-like approach



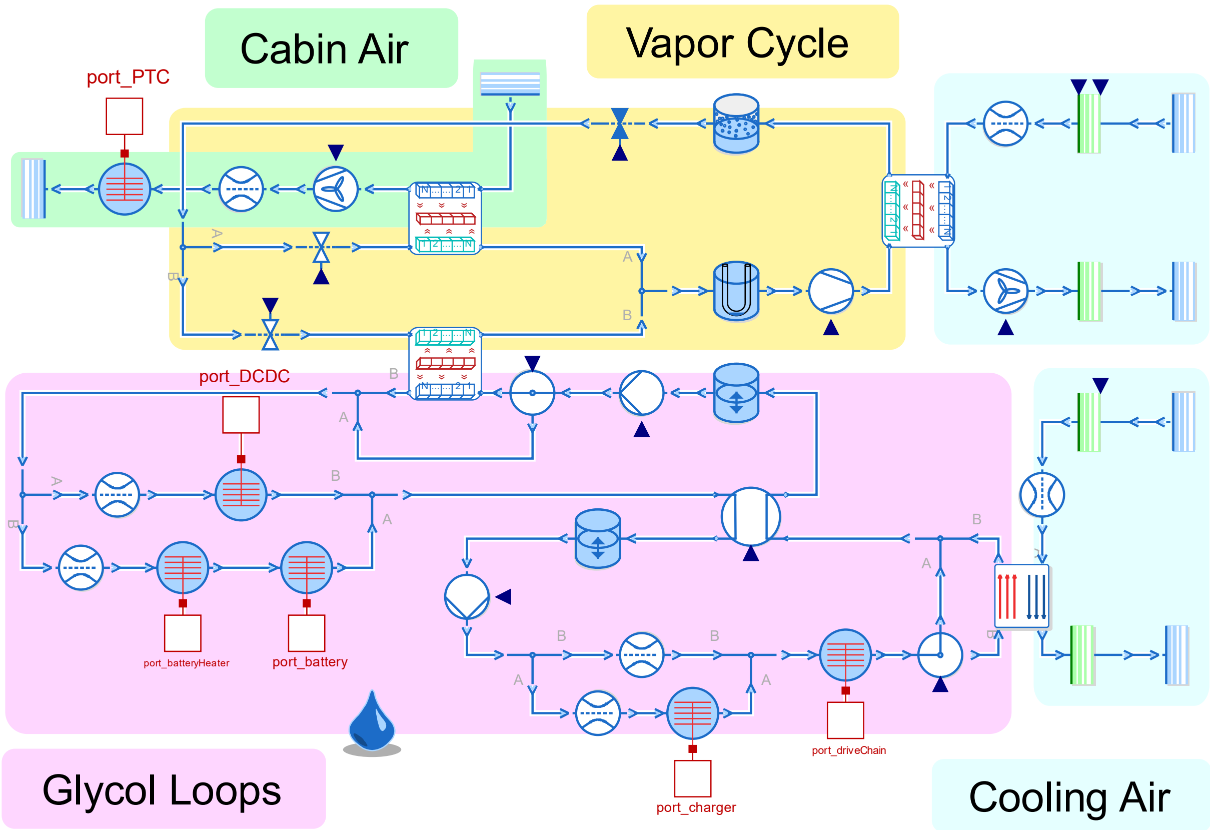
Control of a TFS component to mimic the behaviour of the FMU model

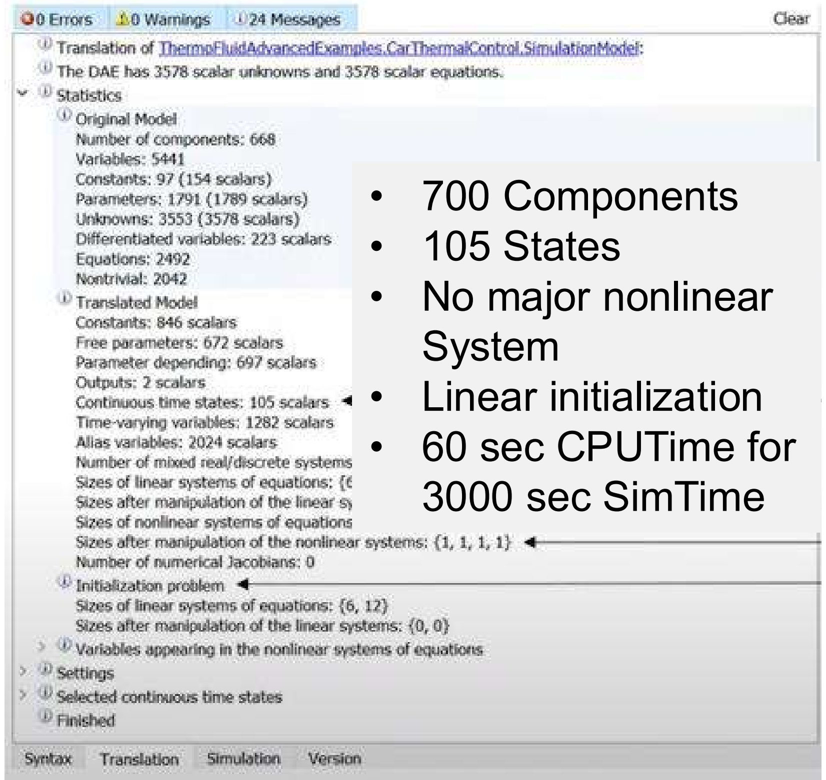


Paper: Gebhart, Raphael and Lepais, Corentin (2025) *Novel Control-like Approach for the Robust Integration of Functional Mock-Up Units into Digital Twins.* Engineering Proceedings, 90 (1), pp. 1-12. Multidisciplinary Digital Publishing Institute (MDPI). doi: 10.3390/engproc2025090012. ISSN 2673-4591

Presentation: Gebhart, Raphael and Lepais, Corentin (2024) *Digital Twin for simulation of Aircraft Thermal Management System architectures in TheMa4HERA.* 14th EASN International Conference, 2024-10-08 - 2024-10-11, Thessaloniki, Greece. (Unpublished)

Thermal Management System of an electric car





- 700 Components
- 105 States
- No major nonlinear System
- Linear initialization
- 60 sec CPUTime for 3000 sec SimTime

Prototypical Controller Robustness