Optimizing System Architectures by Leveraging Collaborative MDO

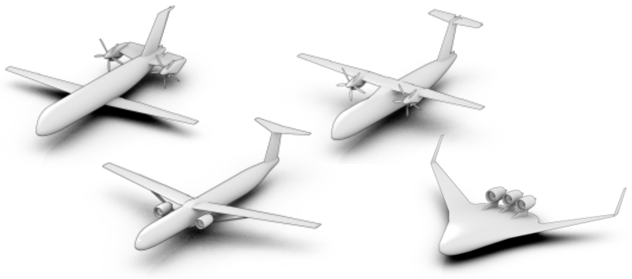
by Jasper Bussemaker
jasper.bussemaker@dlr.de

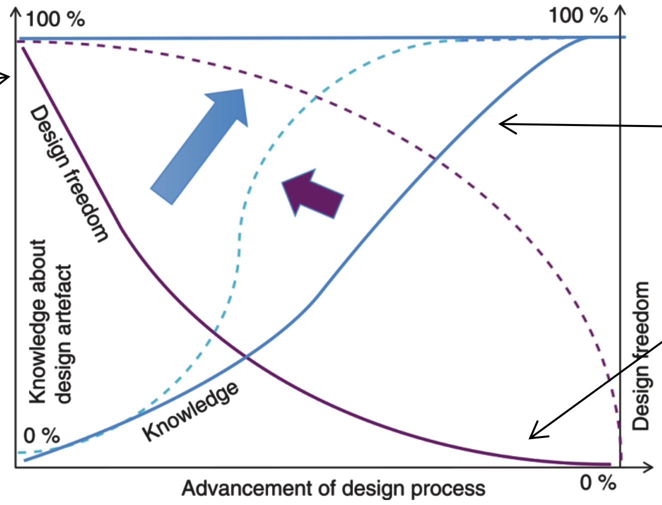
DLR

Trends in Complex System Design

System Architecting

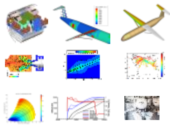
1. High-impact decisions
2. Large design freedom
3. Rough knowledge

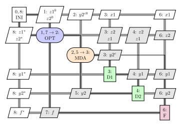


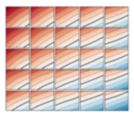


Design Optimization

1. Lower-impact decisions
2. Less design freedom
3. Detailed knowledge







Trends in Complex System Design

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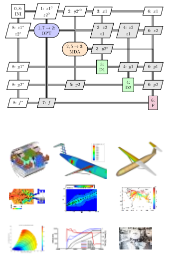
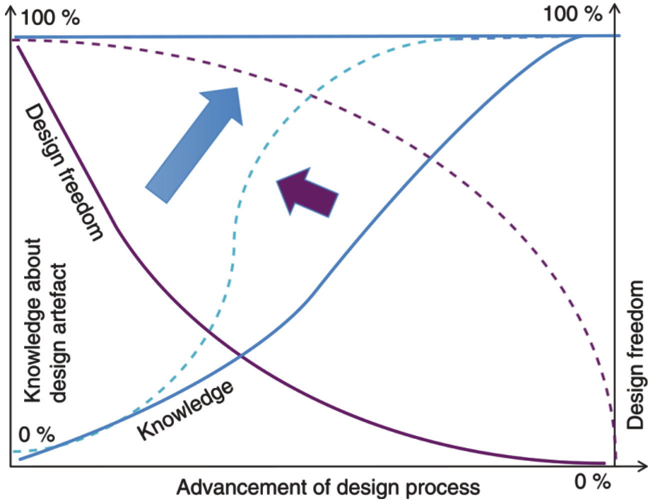
3. Detailed knowledge





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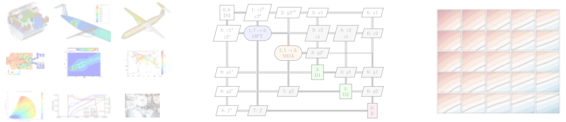
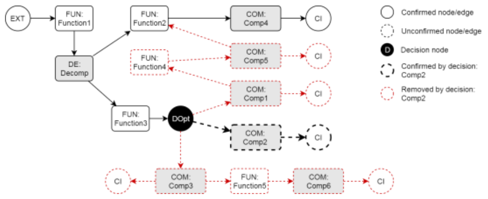
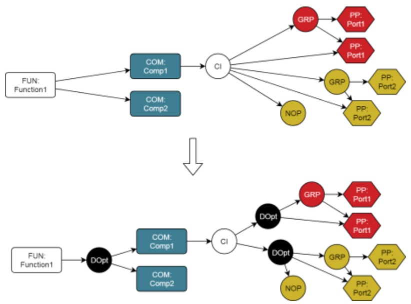


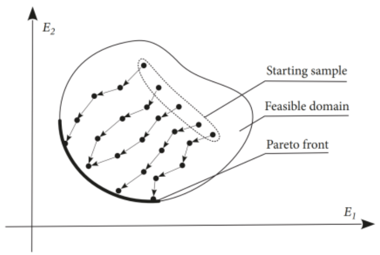
Architecture Optimization Building Blocks

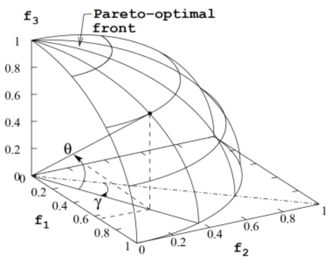
1. Modeling the Design Space
   - Mapping of function-form-structure
   - Identifying design decisions
   - Enable interfaces with MBSE

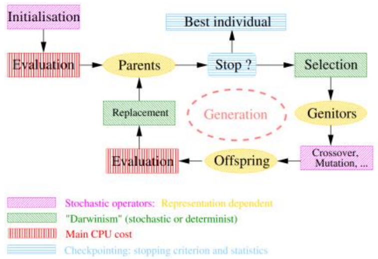




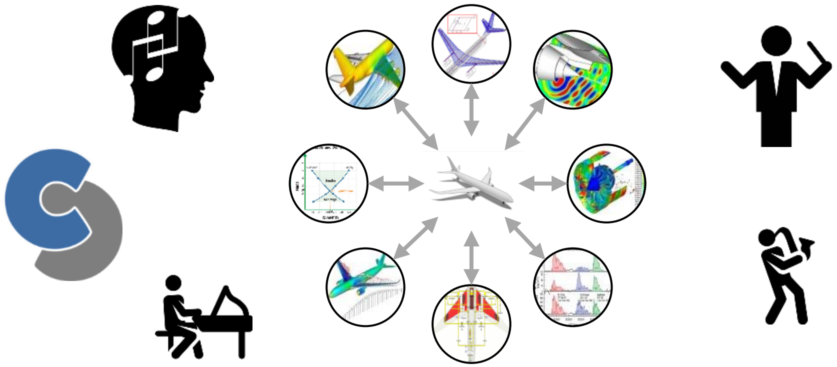
2. Enabling Efficient Optimization
   - Formulating the optimization problem
   - Low number of function evaluations
   - Multi-objective mixed-integer optimization







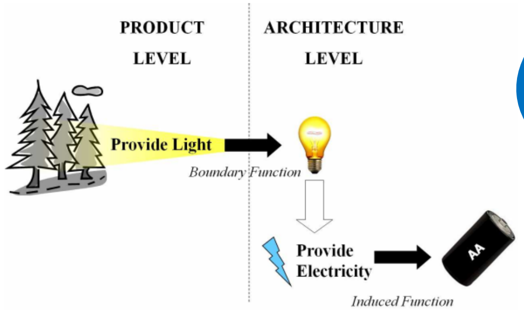
3. Leveraging Collaborative MDO
   - Compatibility with central data schema
   - Manage topology changes
   - Methodology usable by integrators

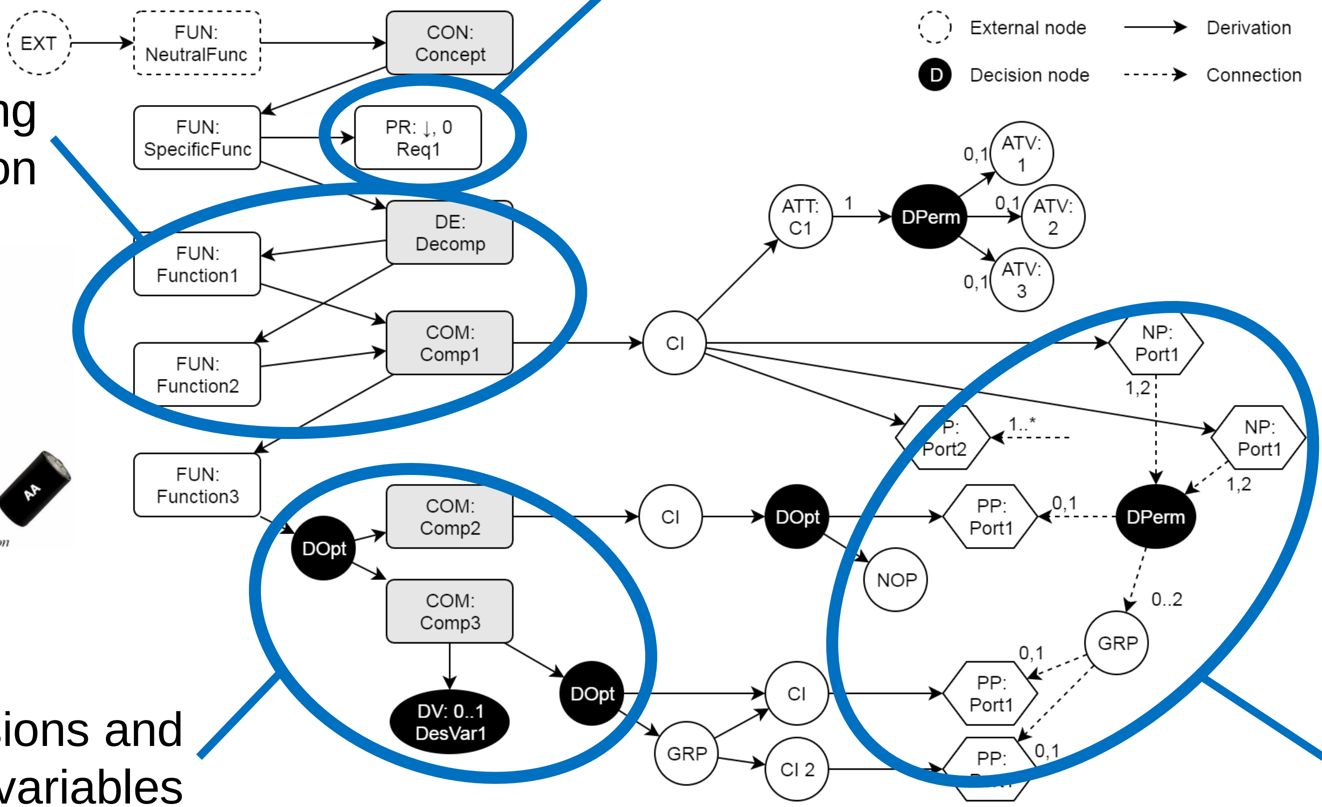


Modeling the Architecture Design Space as a Graph

Performance requirements as objectives or constraints

Function-form mapping and function induction





$$
\begin{aligned}
\mathit{minimize} \quad & f_m(\boldsymbol{x}, \boldsymbol{y}), \\
\mathit{where} \quad & x_i \in \mathbb{R} \\
& y_j \in \mathbb{Z} \\
\mathit{w.r.t.} \quad & g_k(\boldsymbol{x}, \boldsymbol{y}) \leq 0, \\
& x_i^{(L)} \leq x_i \leq x_i^{(U)}
\end{aligned}
$$

Explicit design decisions and additional design variables

Structure using port connections and permutation decisions

Optimization Problem Characteristics

- Discrete architecture decisions
- Continuous sizing parameters

Hierarchical, **mixed-integer**, **multi-objective** optimization

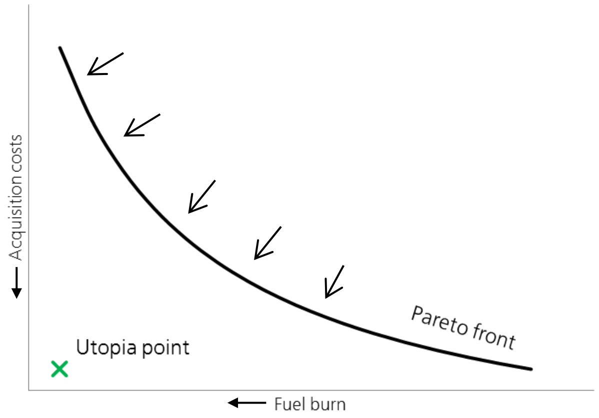
Conditionally active design variables

Example: strut or not?

Strut? Yes
Where to place strut?

Strut? No
~~Where to place strut?~~

- Conflicting stakeholder requirements
- No a-priori objective weighting



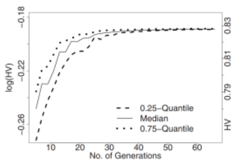
Efficient Optimization Needs and Strategies

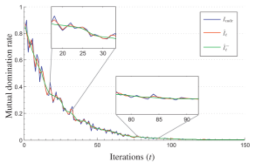
Problem

- High-dimensional multi-objective design space
- Cannot use gradient-based methods
- Could use evolutionary optimization algorithms
  - Requires many function evaluations
- Function evaluations are time/resource intensive!

Solution strategies

1. Detect convergence
2. Model-building optimization
3. Architecture preselection

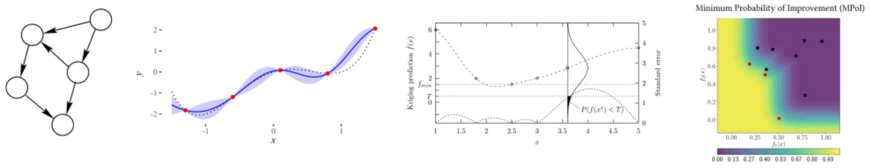




Model-building optimization

1. Build model of design space
2. Use model to find new promising design points

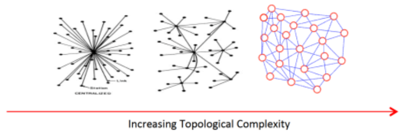
- Surrogate modeling (e.g. Kriging, EGO)
- Probabilistic modeling (e.g. Bayesian Networks)

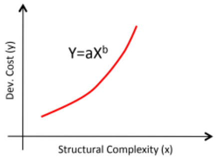


Architecture preselection

- Cheap-to-evaluate proxy-objectives and proxy-constraints (proxy-metrics)
- Complexity metrics as representation of development costs
- TRL-based metrics

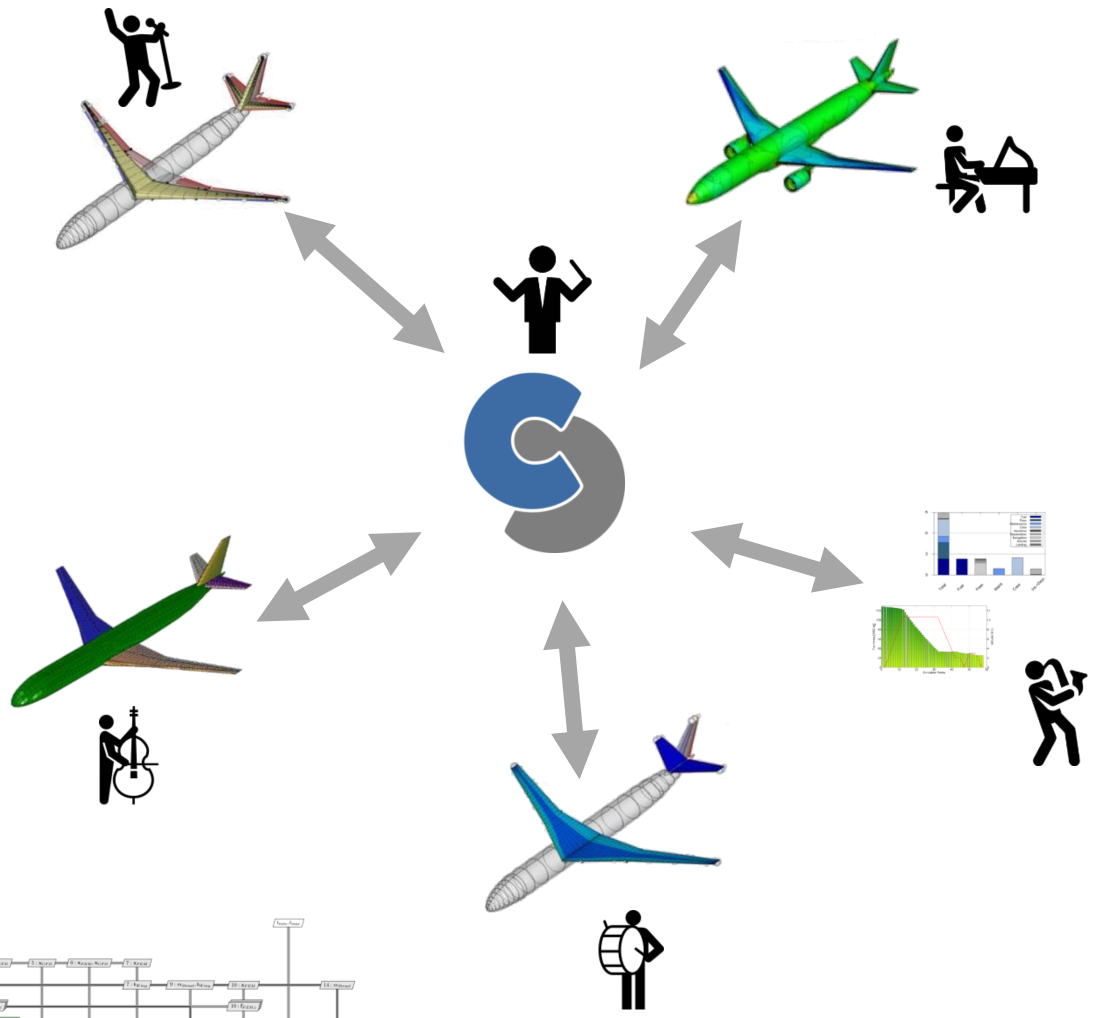
$$M(A) = n + \frac{1}{n}\sum_{i=1}^{n} z_i$$





Leveraging Collaborative MDO

1. Many disciplines involved in complex product design
2. Distributed expert knowledge
3. System integrator has overview, but no expert knowledge

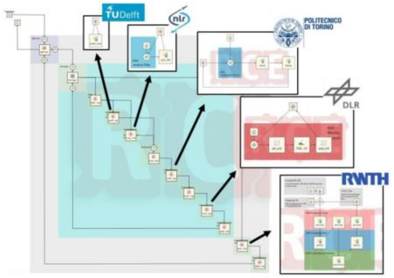


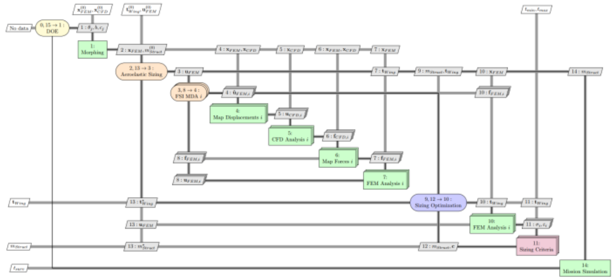
Collaborative MDO

- One data language (e.g. CPACS)
- Data transfer between organizations
- MDO workflow modeling techniques

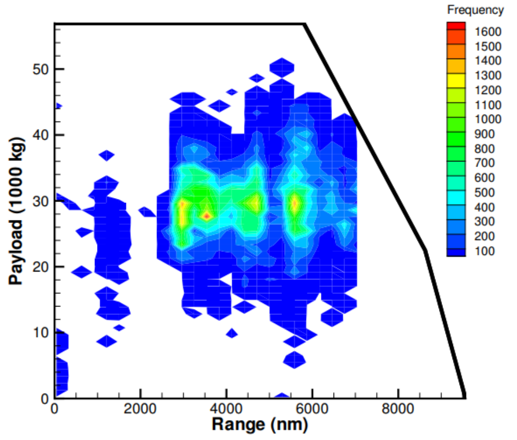
AGILE

AGILE 4.0

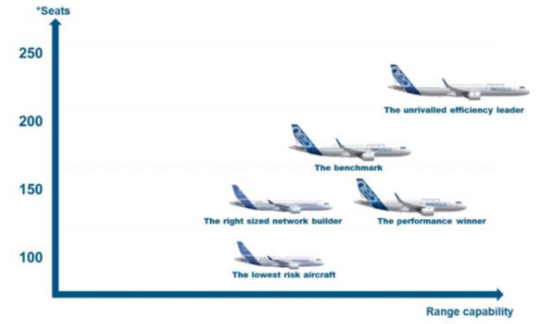


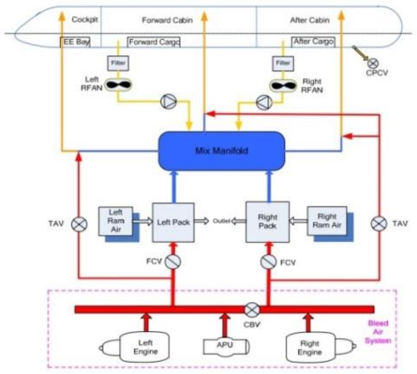


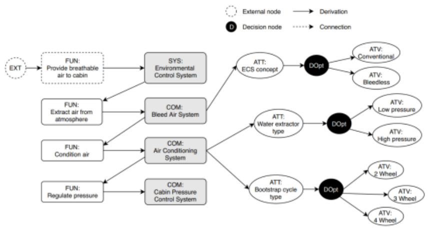
Test Design Problem:
Onboard System Architecture Optimization from a Family Concept Perspective

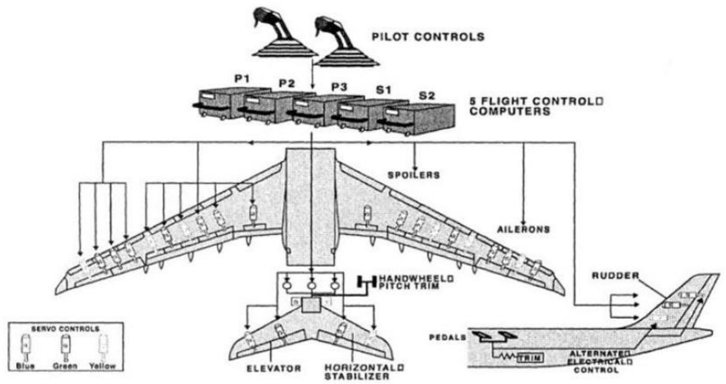


Design an aircraft family for a specific market segment





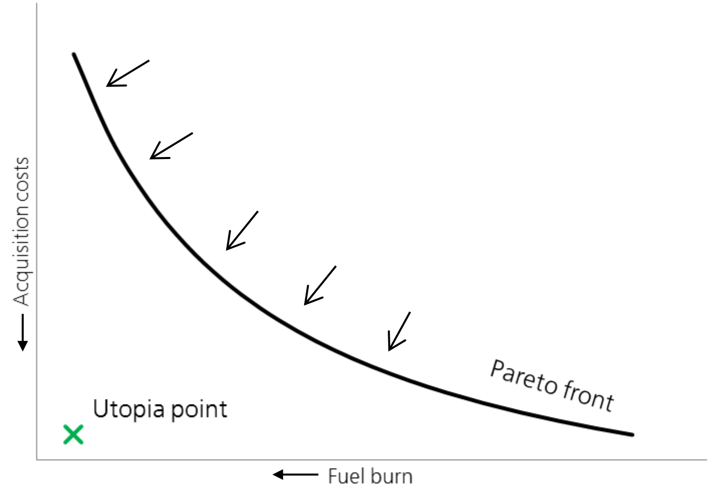




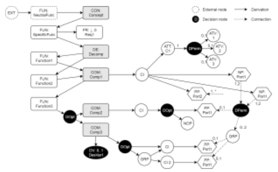
Optimize:
- Environmental Control System architecture
- Flight Control System architecture
- Commonality among family members

Tradeoff:

Acquisition costs vs operating costs (fuel burn)

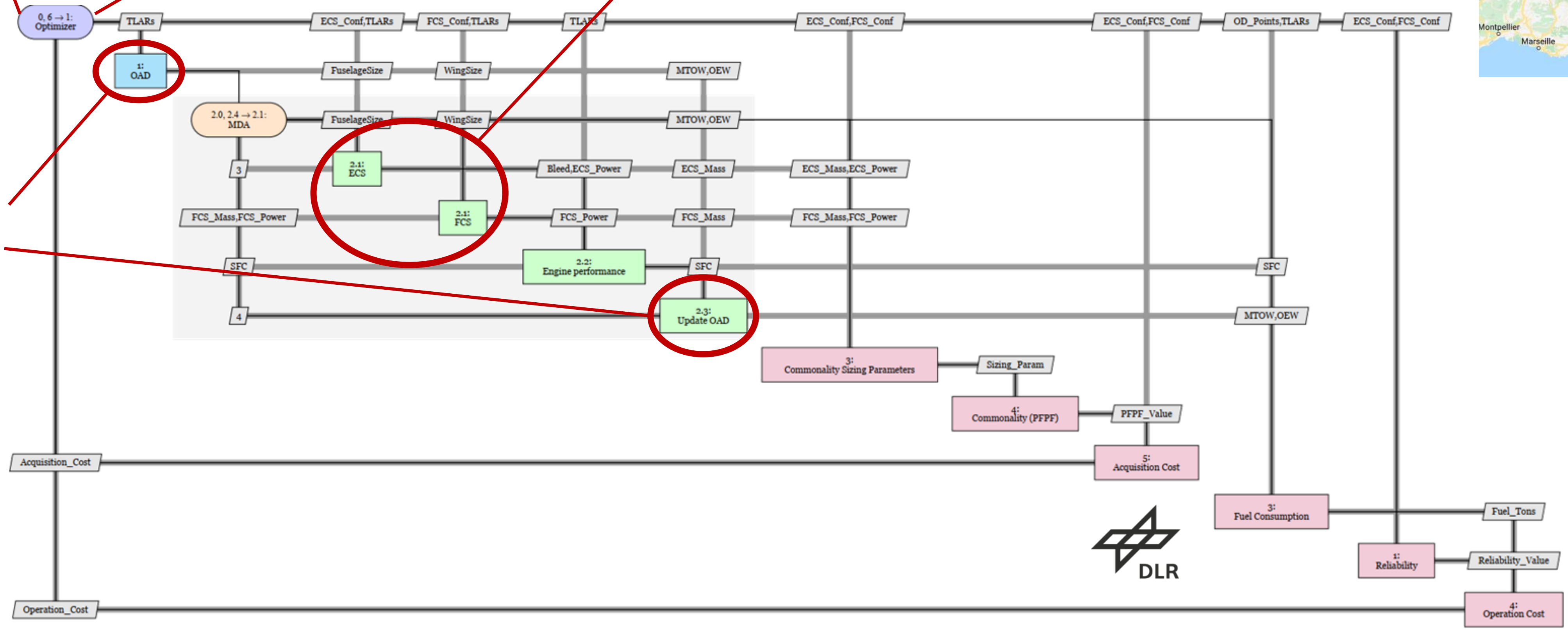


Preliminary Collaborative XDSM



POLITECNICO DI TORINO

ASTRID



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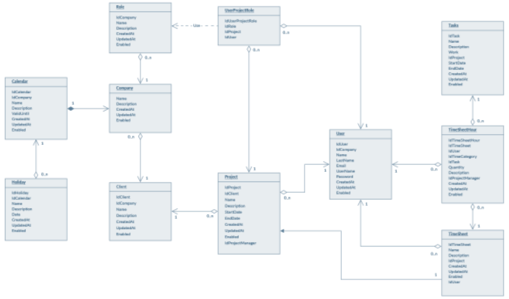
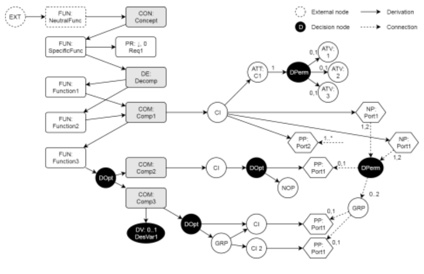
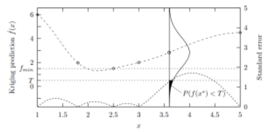
Next Steps

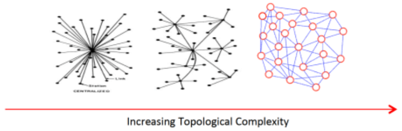




Design Space Modeling

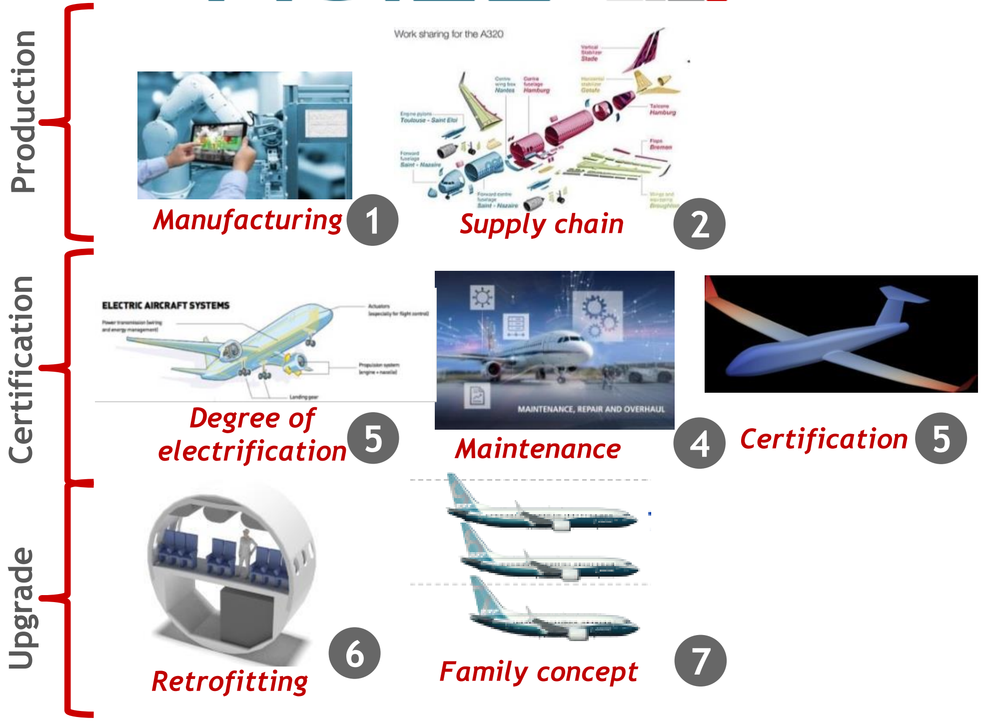
- Intuitive GUI
- Formalization





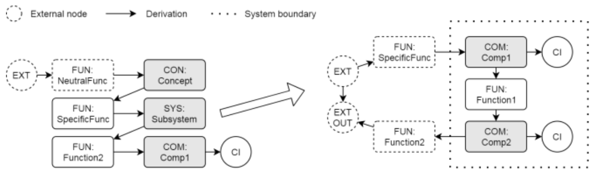
Architecture Optimization

- Benchmark Architecture Optimization Problem
- Algorithm Development
- Preselection Proxy-Metrics



Collaborative Architecture Optimization

- Reusable graph to common language conversion
- Impact of topology changes
- Apply in AGILE 4.0 use cases
- Additional test cases:
  - System-of-Systems
  - Hybrid Electric propulsion



Thank you!
Questions?