Optimizing System Architectures by Leveraging Collaborative MDO

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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

**System Architecting**
1. High-impact decisions
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**Architecture Optimization**
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3. Detailed knowledge
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

- Function-form mapping and function induction
- Explicit design decisions and additional design variables
- Performance requirements as objectives or constraints
- Structure using port connections and permutation decisions

\[
\text{minimize } f_m(x, y), \quad \text{where } x_i \in \mathbb{R}, \quad y_i \in \mathbb{Z}
\]

\[
\text{w.r.t. } g_k(x, y) \leq 0, \quad x_i^{(L)} \leq x_i \leq x_i^{(U)}
\]
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

\[ M(A) = n + \frac{1}{k} \sum_{i=1}^{k} z_i \]
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
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
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?