DYNAMIC FORMULATION AND EXECUTION OF MDAO WORKFLOWS FOR ARCHITECTURE OPTIMIZATION

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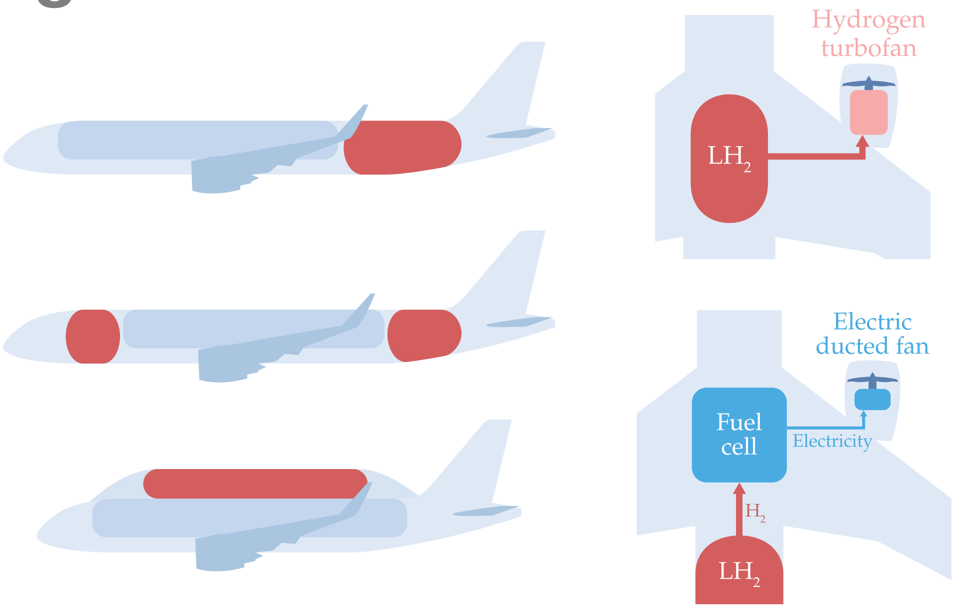
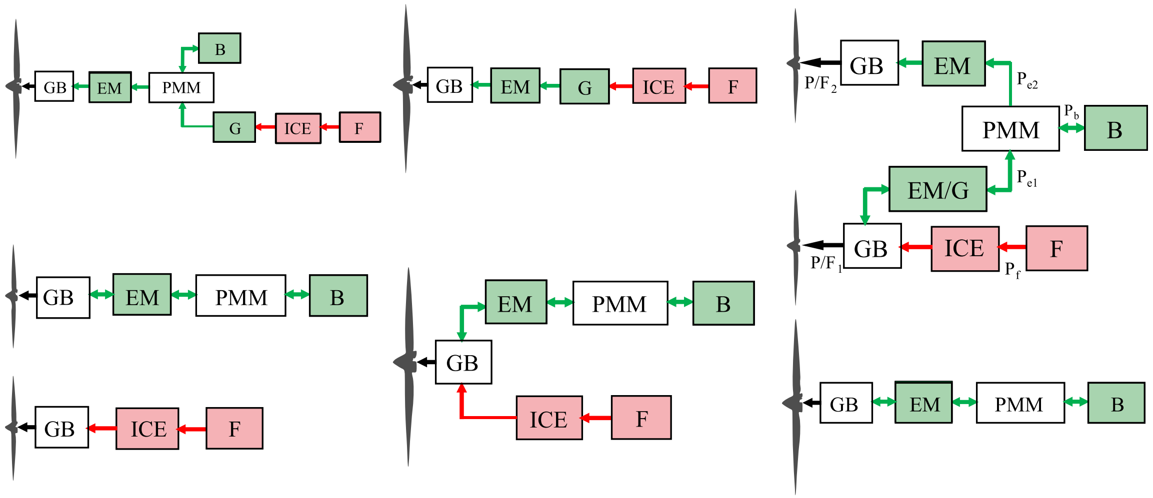
Complex Systems Design Challenges

- Systems are subjected to stricter constraints to integrate **more disruptive** technologies
- Many possible **architectural solutions**
  - Technology selection, function allocation, component arrangements, sizing parameters, etc.
  - Non-linear and non-trivial performance impacts
- Need a method that:
  - **Automatically** searches the design space for the “best” design solution
  - Applies **multidisciplinary** simulation and analysis

➢**System Architecture Optimization (SAO)**





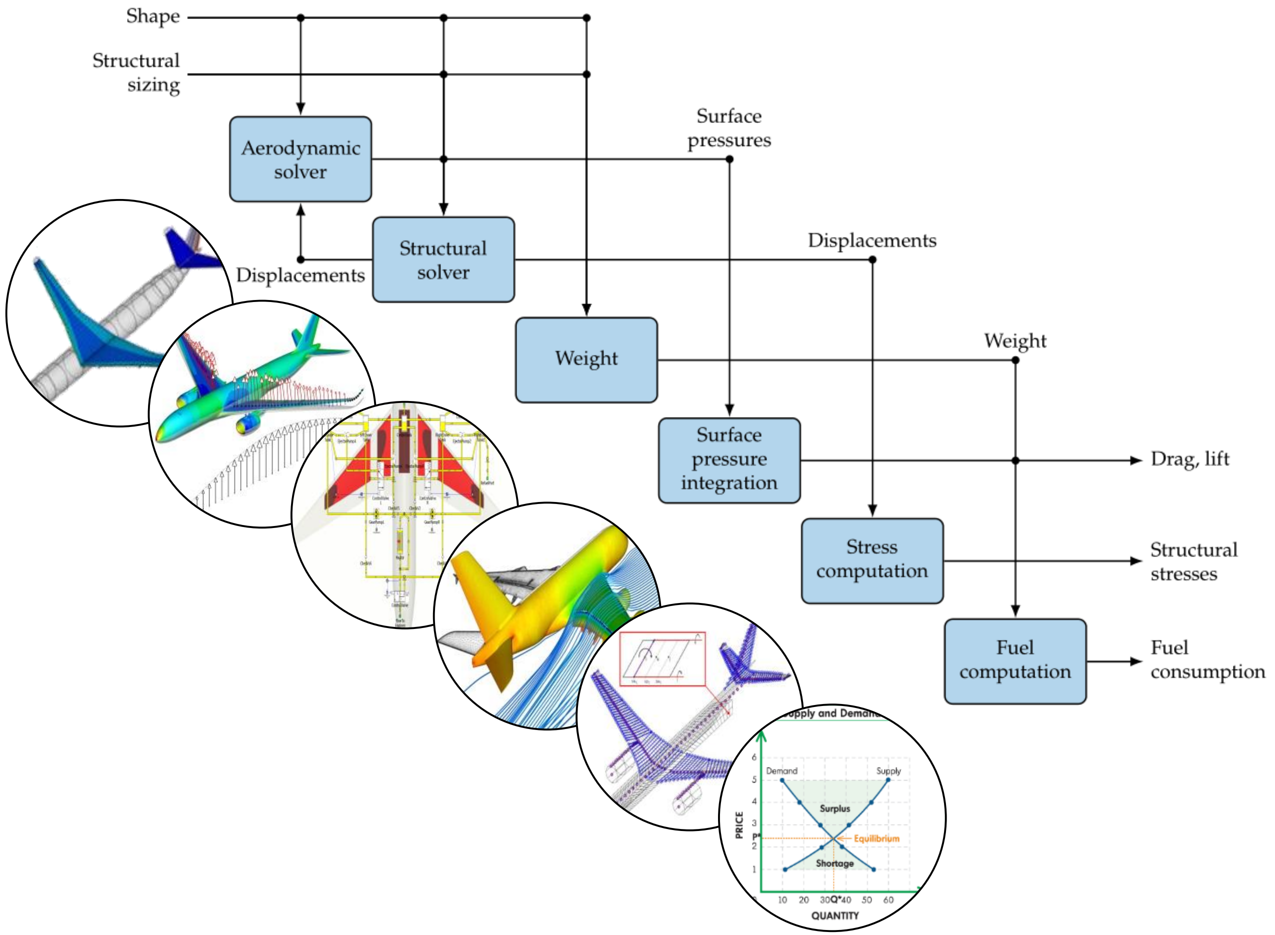
Figures from:
Adler and Martins. "Hydrogen-powered aircraft: Fundamental concepts, key technologies, and environmental impacts". In: Progress in Aerospace Sciences 141 (Aug. 2023), p. 100922
Salem, Palaia, and Quarta. "Review of hybrid-electric aircraft technologies and designs: Critical analysis and novel solutions". In: Progress in Aerospace Sciences 141 (Aug. 2023), p. 100924

Quantitative Architecture Evaluation

- Systems engineering is a fundamentally holistic discipline
  - Should consider all involved stakeholders and engineering disciplines and their influence on the design

- Physics-based analysis for novel systems
  - Cannot rely on previous experience

➢ **Multidisciplinary Design Analysis and Optimization (MDAO)**



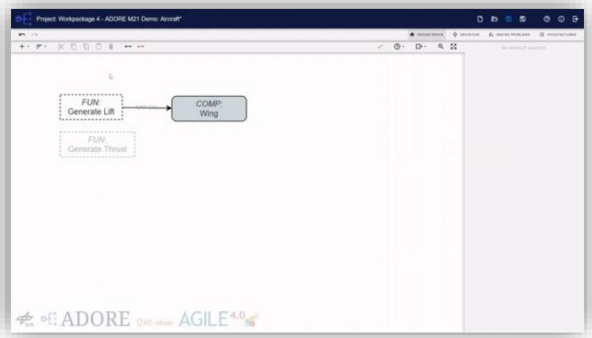
DLR's System Architecture Optimization (SAO) and MDAO Methodology and Tools

DLR

Up-Stream

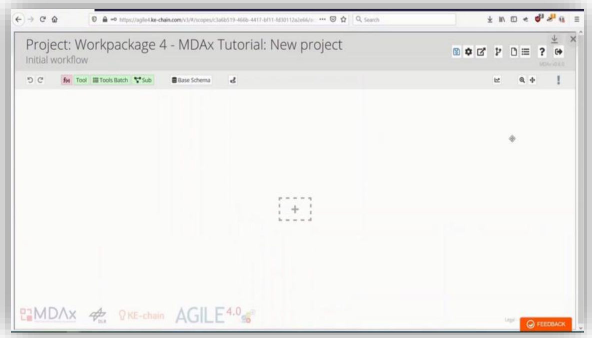
Stakeholder Analysis, Requirements Management, …

ADORE



- Collect functional requirements
- Allocate boundary functions to components
- Model architectural choices
- Natural transition from problem to solution
- Less prone to solution bias
- Directly traceable to requirements

MDAx
MDO Workflow Design Accelerator



- Easy-to-use interface for defining I/O
- Intuitive and responsive XDSM-based user interface
- Data connection inspection and editing
- Continuous feedback on workflow status
- One-click export to PIDO platform

Down-Stream

Analysis, Visualization, Decision Making, …

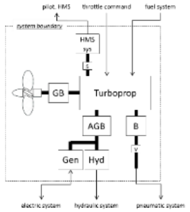
Bridge between System Architecture Optimization (SAO) and MDAO

DLR's Strategy

ADORE

MDAx
MDO Workflow Design Accelerator

Different system architectures…

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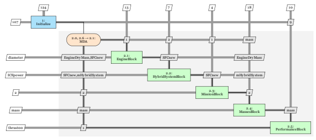


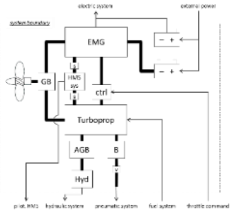

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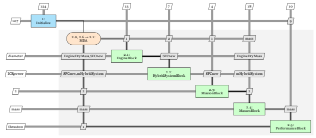

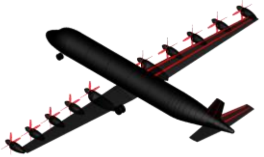
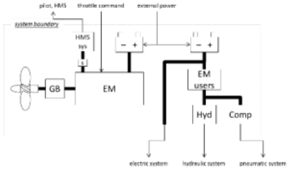

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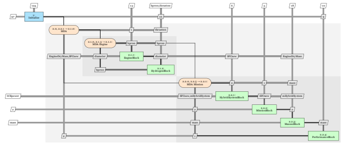


…need different MDAO workflows

High effort to manage multiple workflows….

What if the design space contains 100 architectures? 1,000? 1,000,000?

Objective: develop a method to
- ➢ automatically adjust MDAO workflow behavior
- ➢ for each system architecture

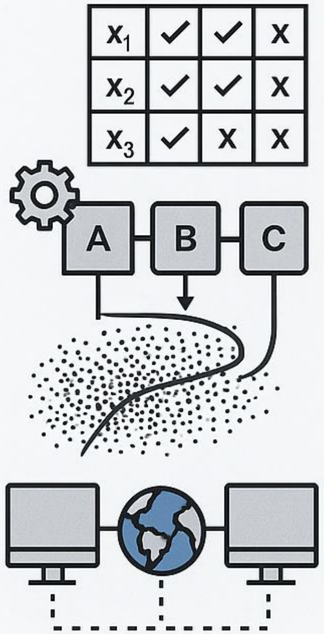
"Dynamic MDAO"

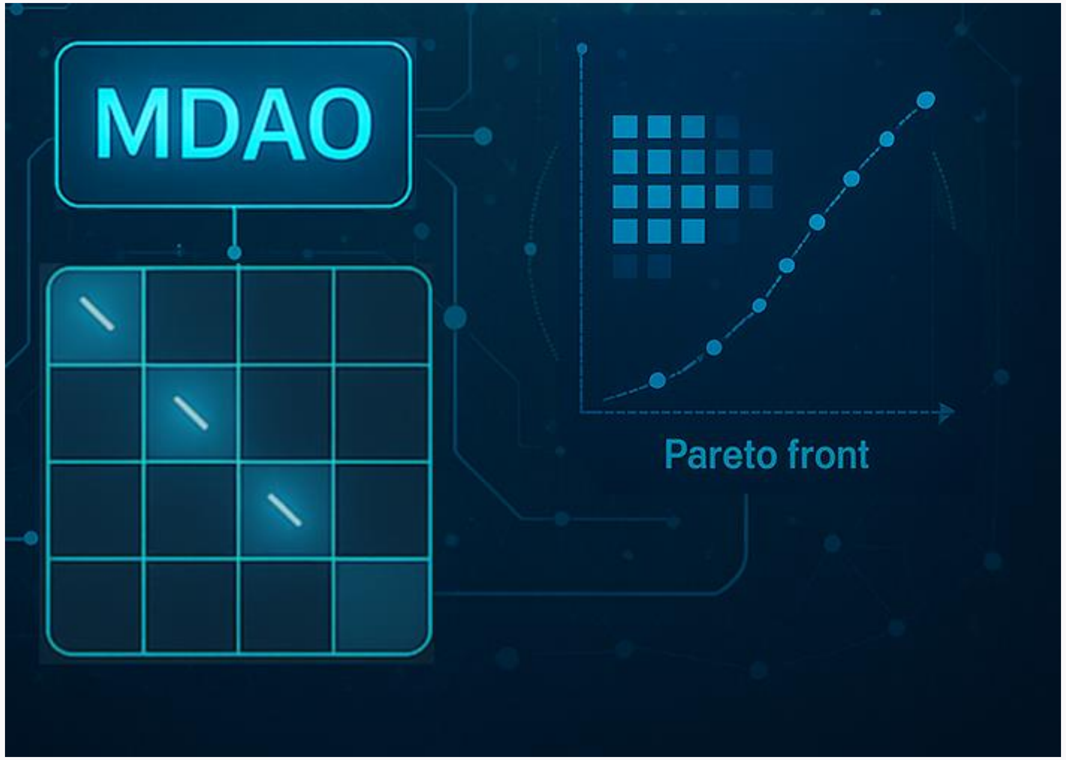
More info:
Garg, Sparsh & Sánchez, Raúl & Bussemaker, Jasper & Boggero, Luca & Nagel, Björn. (2024). Dynamic Formulation and Execution of MDAO Workflows for Architecture Optimization. 10.2514/6.2024-4402.

PROBLEM STATEMENT

Challenges with Traditional MDAO

- Fixed variable sets and data connections
- Manual reconfiguration for each architecture
- High risk of error in large design spaces
- Incompatible with collaborative, distributed workflows

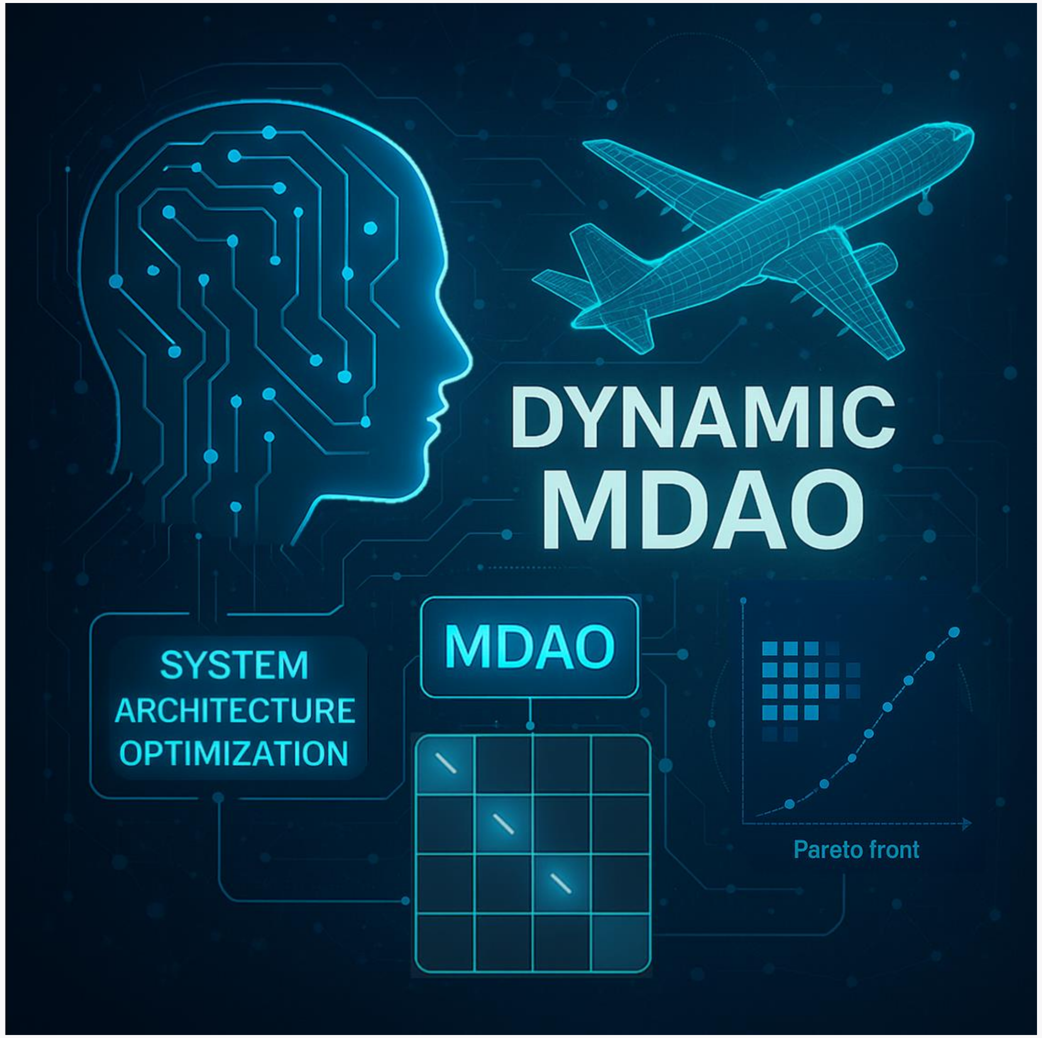




Motivation

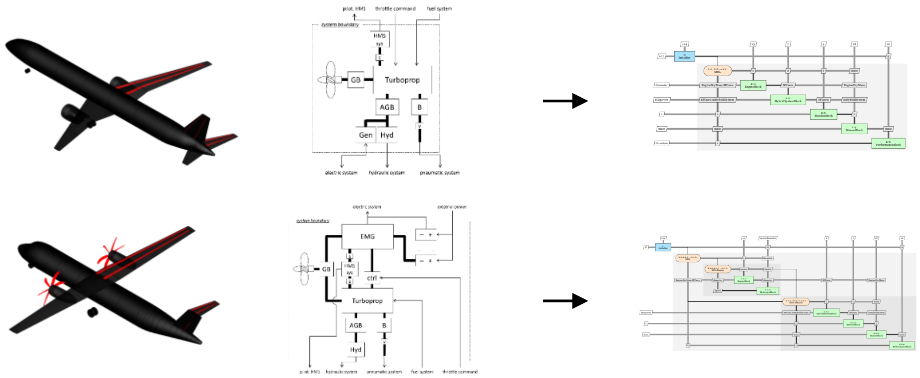
Why do we need Dynamic MDAO?

- Complexity in early design phases
- SAO demands evaluation of many architecture variants
- Traditional MDAO workflows = static, inflexible
- Need for automation, flexibility, and traceability

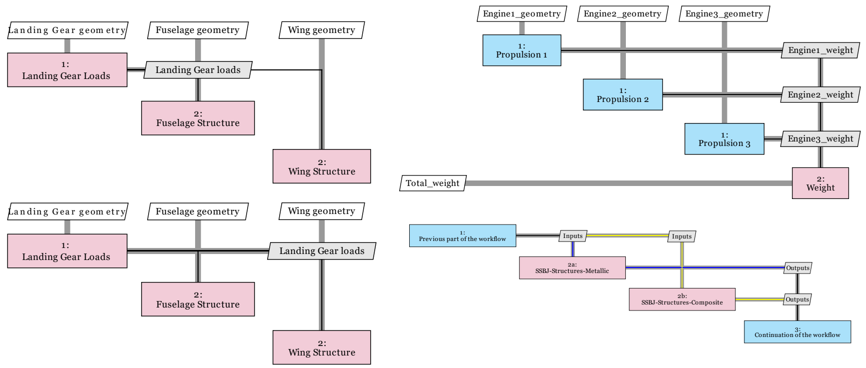


Main Questions

- How do changes in system architecture **influence** the MDAO workflow?

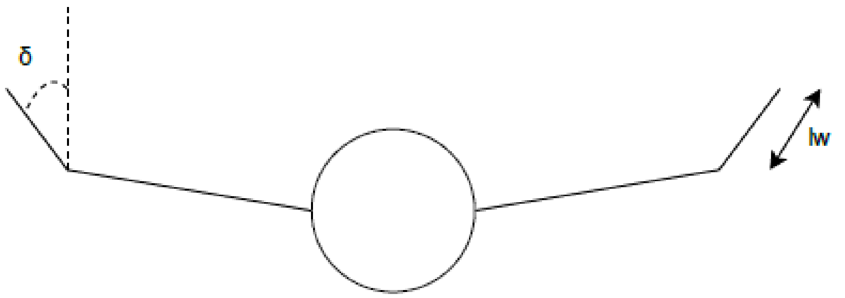


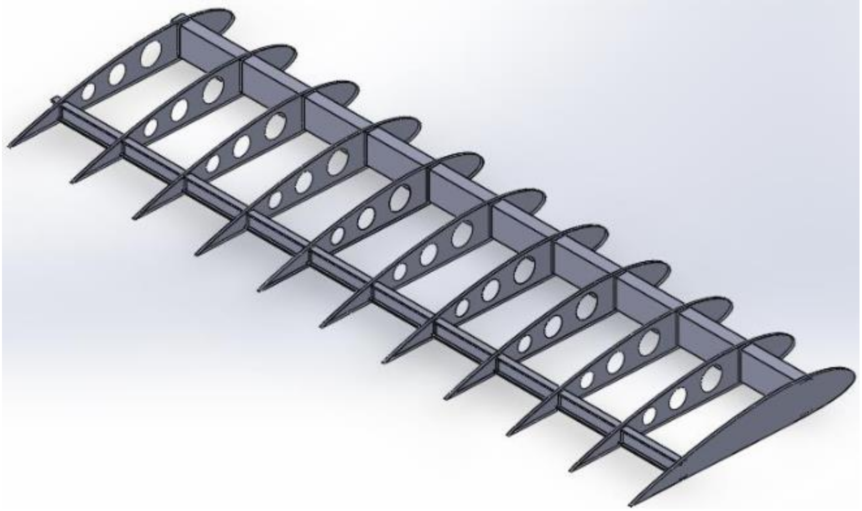
- How to **support** such influences in MDAO workflows?



Influence 1: Conditional Variables

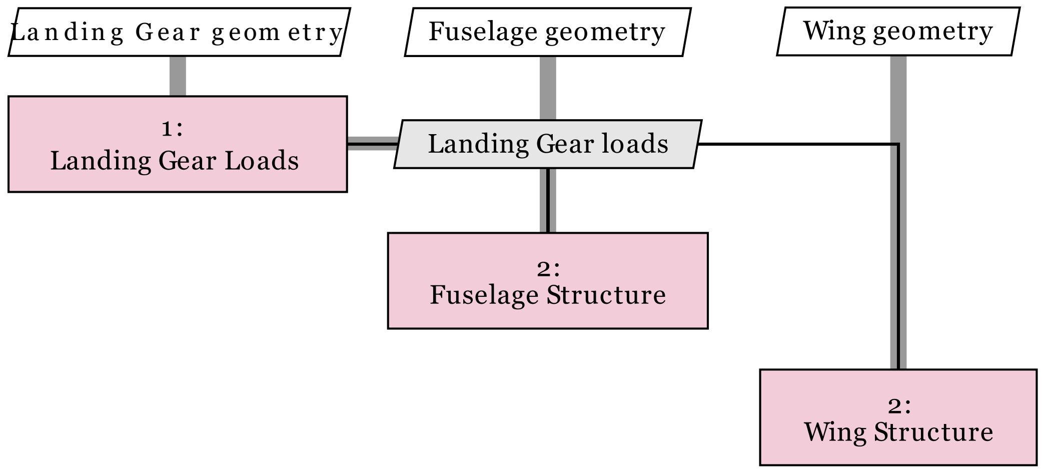
- Conditional variables:
  - Variables whose existence in the MDO problem depend on an architectural decision
  - Example scenario: component-specific variables, depending on whether that component is selected or not
- Also applies to more complex data structures
- Examples:
  - Winglet inclusion choice
  - Number of ribs



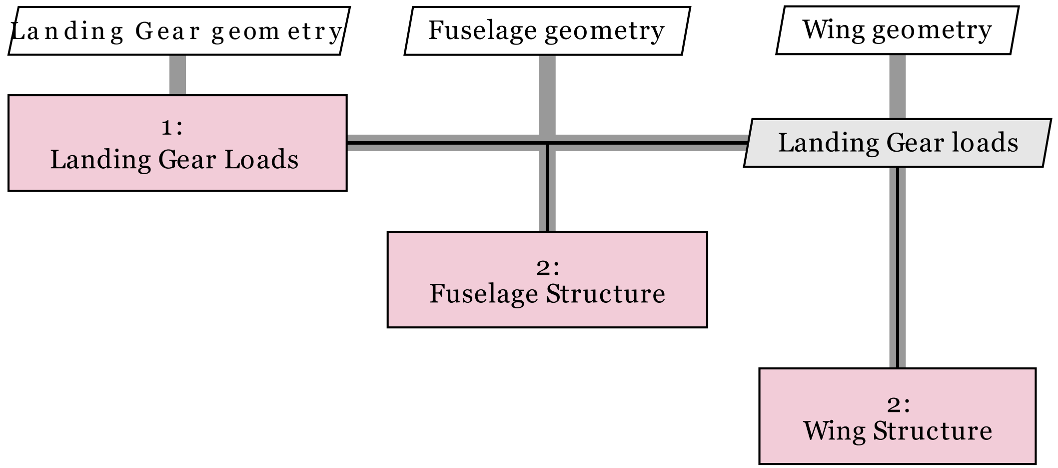


Influence 2: Data Connection

- Data connection:
  - Connections between design disciplines might change because of an architectural decision
  - Example scenario: changes in function allocation



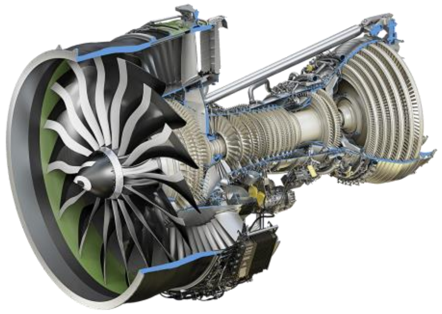
- Example: landing gear placement

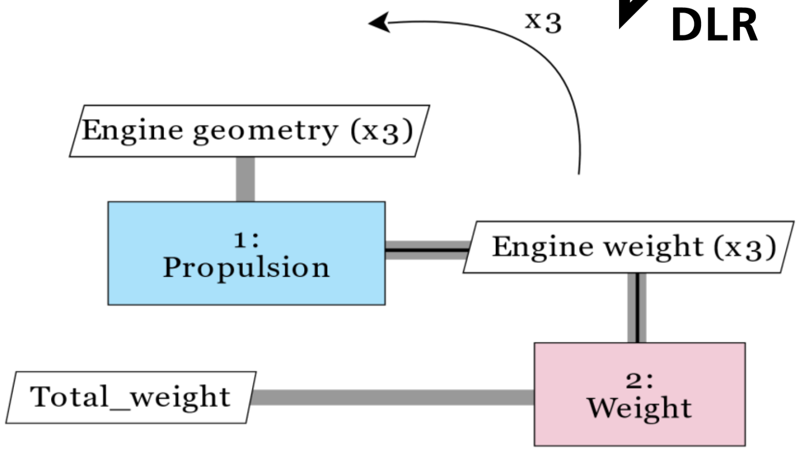


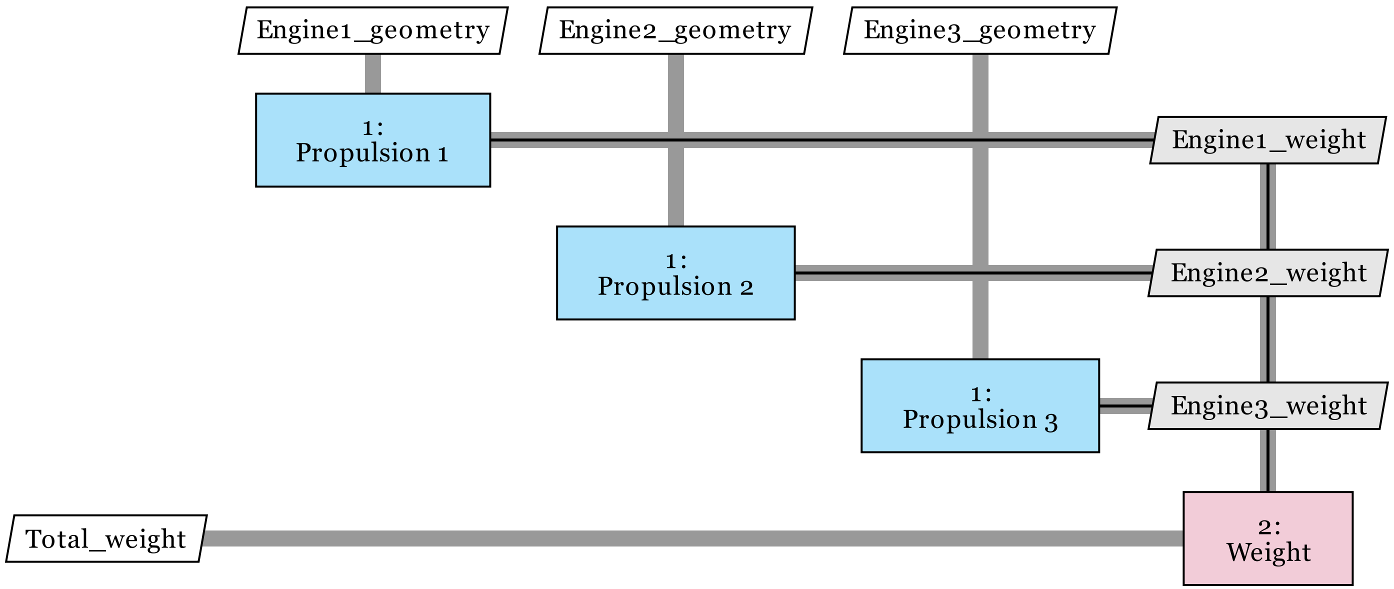
Influence 3: Discipline Repetition

- Discipline repetition:
  - Disciplines might have to be repeated a different number of times depending on the architecture
  - Example scenario: components can be instantiated multiple times, a discipline needs to be executed for each instance
- Variables and connections may change for each iteration

- Example: number of engines
- Series or parallel configuration

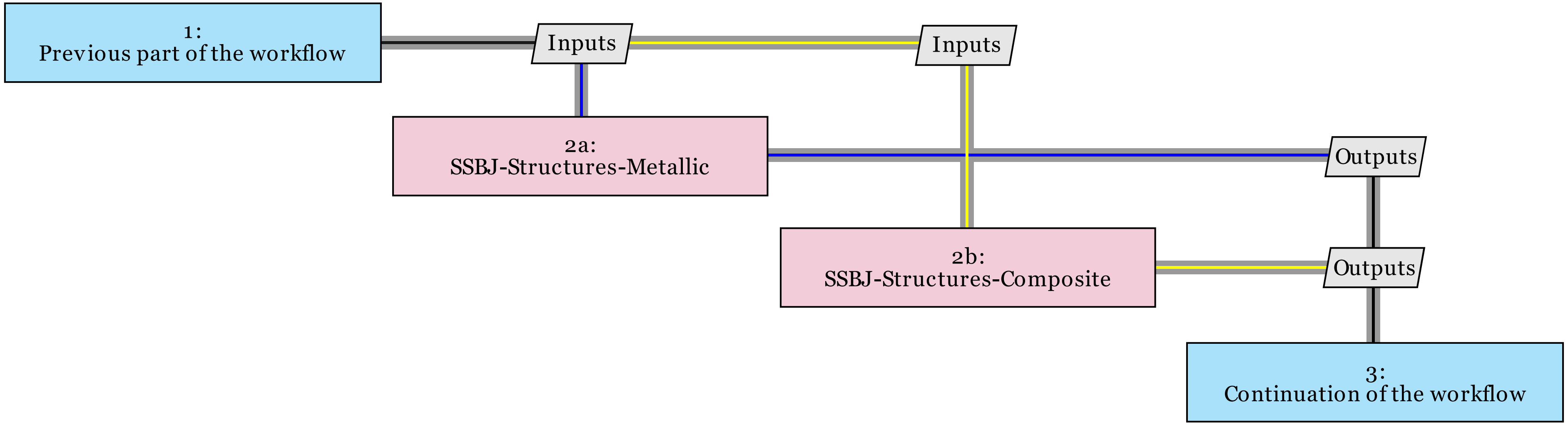




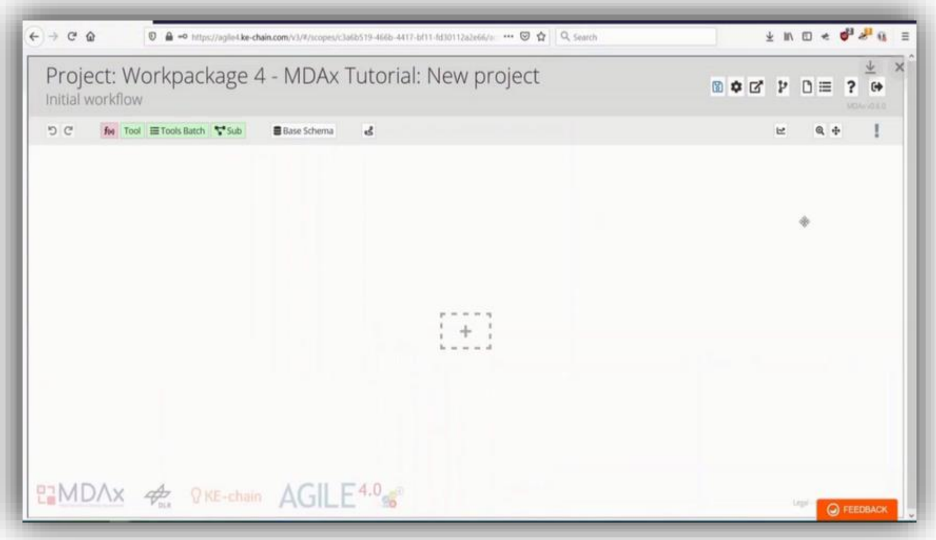


Influence 4: Discipline Activation

- Discipline activation:
  - Disciplines in the workflow might be needed or not depending on an architecture choice
  - Example scenario: technology selection choice requiring different calculations
- Example: fuselage material choice



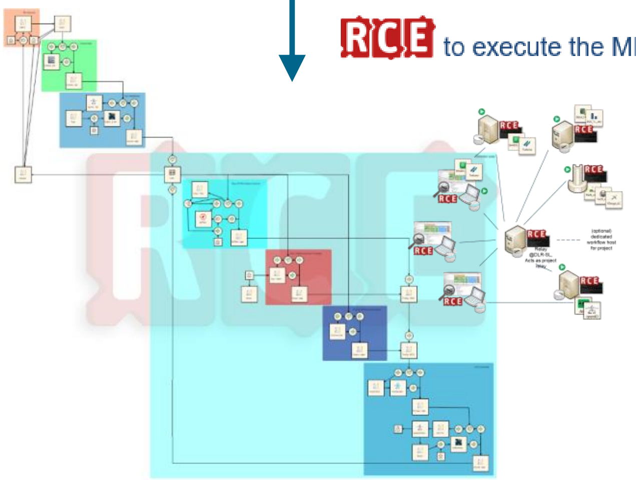
MDAO Process Modeling and Deployment



cpacs as common language

MDAx to set-up the MDO problem

RCE to execute the MDO problem



MDO Workflow Design Accelerator

- Easy-to-use interface for defining Input and Output of available models
- Intuitive and responsive XDSM-based user interface
- Data connection inspection and editing
- Continuous feedback on workflow status
- One-click export to RCE

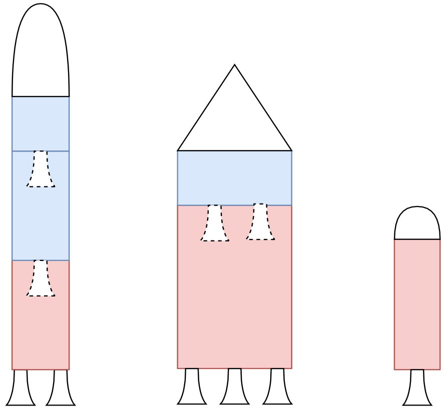
- Open access: https://mdax.mbse-env.com/light/
- Limited functionality for non-commercial use
- **Full access request**, question, queries, collaboration: mdax@dlr.de

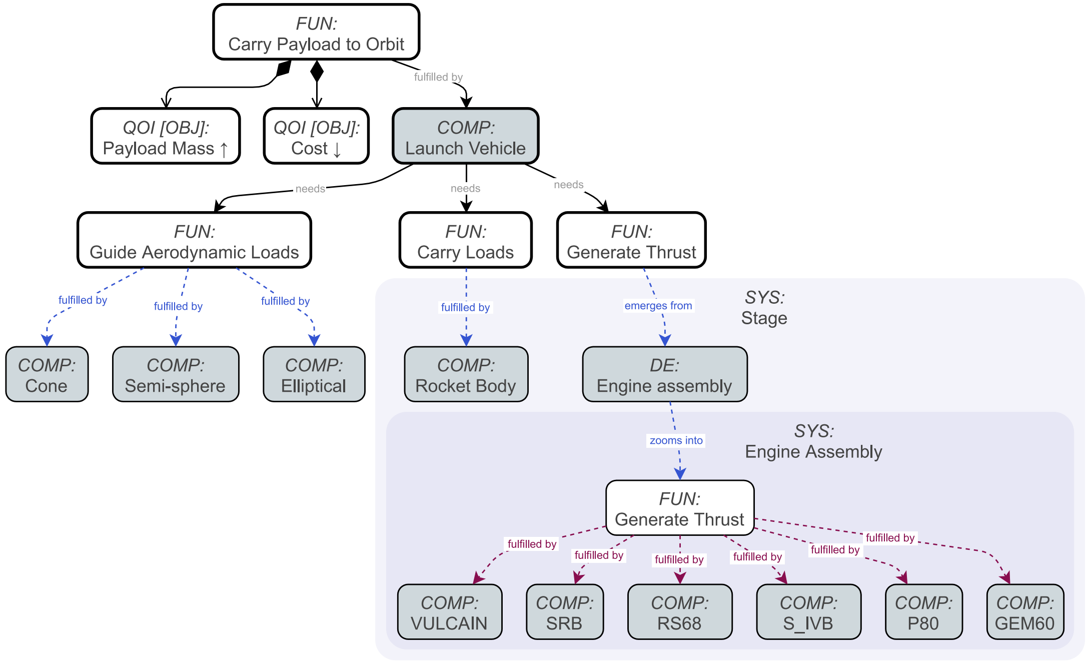
MDAx light MDO Workflow Design Accelerator

Application Case: Launch Vehicle Architecture

- Maximize m_payload
  Minimize Cost
  w.r.t. n_stages ∈ {1, 2, 3}
  n_engines,i ∈ {1, 2, 3}, i = 1, ..., n_stages
  EngineType_i ∈ {SRB, P80, GEM60, VULCAIN, RS68, SIVB}, i = 1, ..., n_stages
  0 ≤ l_stage,factor,i ≤ 1, i = 1, ..., n_stages
  10 ≤ LDRatio ≤ 11
  HeadShape ∈ {Cone, Ellipse, SemiSphere}
  - If Cone: 28 ≤ ConeAngle ≤ 32
  - If Ellipse: 0.15 ≤ LengthRatio ≤ 0.21

  subject to ΔV Margin ≤ 0
  StructuralMargin ≤ 0
  VolumeMargin ≤ 0





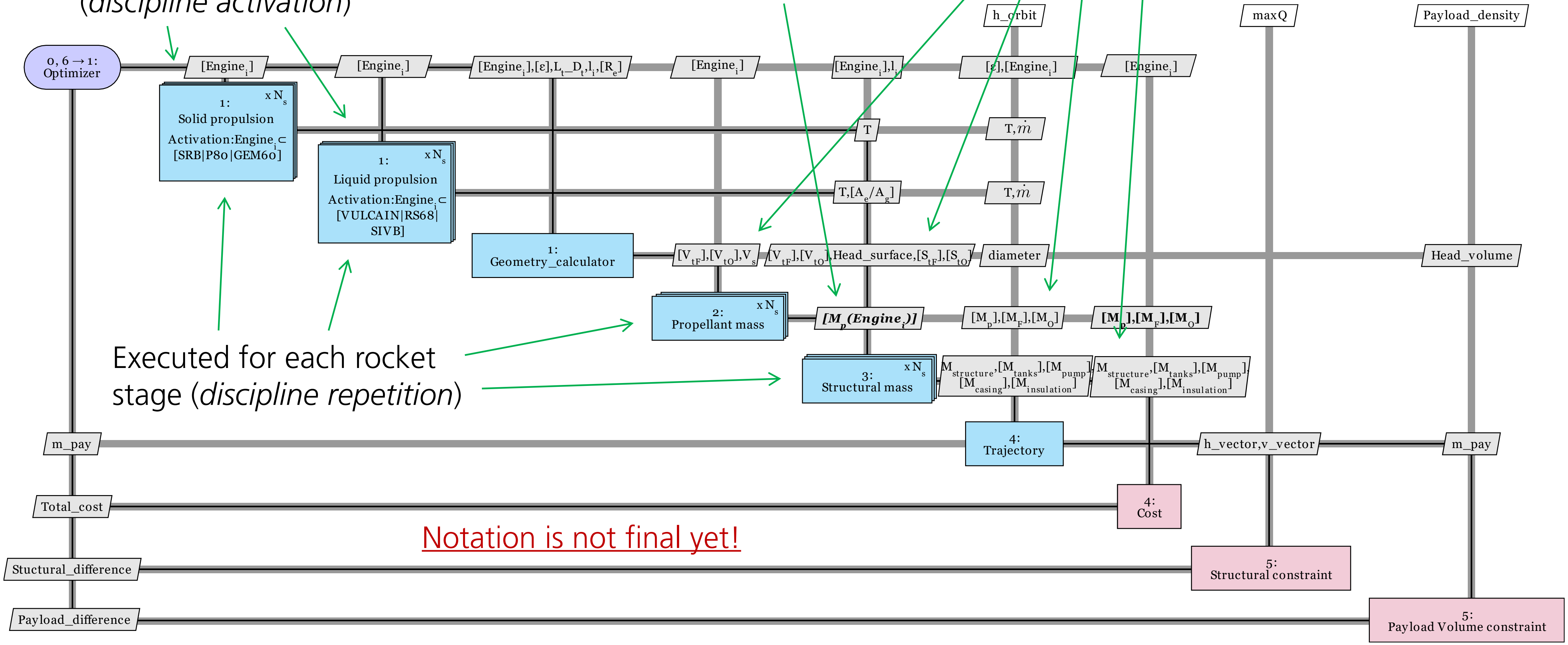
- 18,522 possible design architectures
  - ➢ Infeasible to manage separate MDAO workflows

Launch Vehicle XDSM

Activated based on propulsion type (*discipline activation*)

Connection established based on propulsion type (*data connection*)

Various parameters that only exist based on propulsion type and head shape (*conditional variables*)

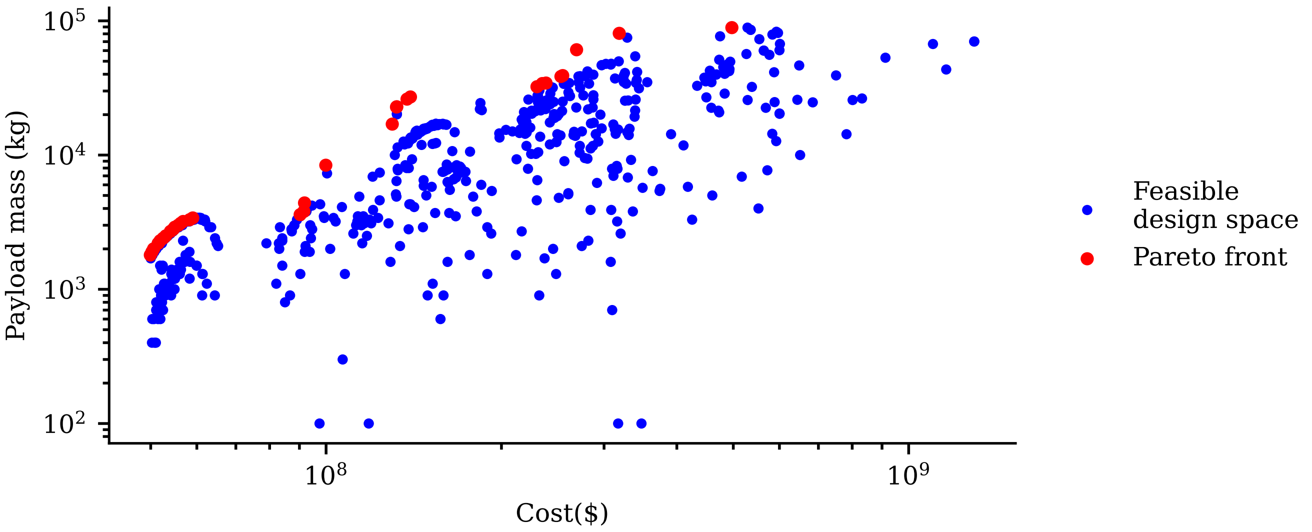


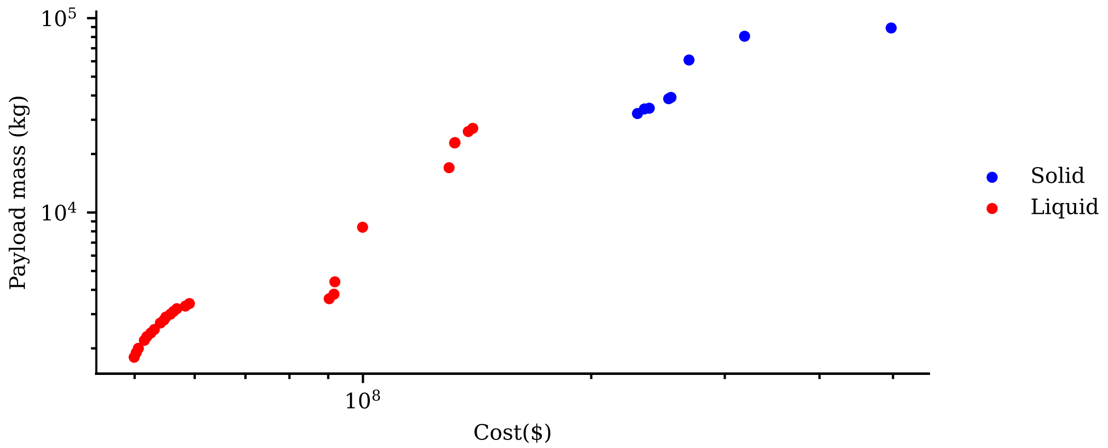
Executed for each rocket stage (*discipline repetition*)

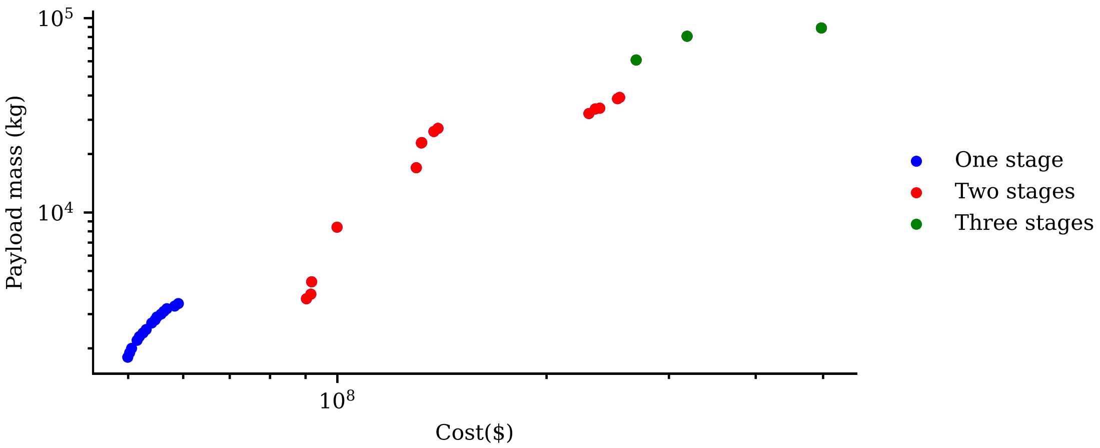
Notation is not final yet!

Launch Vehicle Architecture Optimization Results

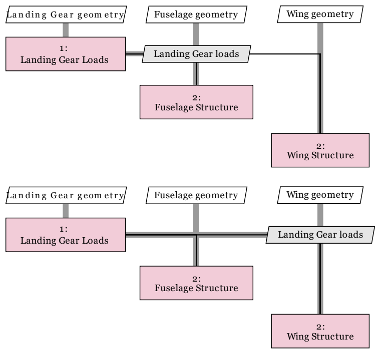
- Optimized using NSGA-II
  - Evaluation budget: 4500
- 763 feasible architectures
- 32 designs in Pareto front

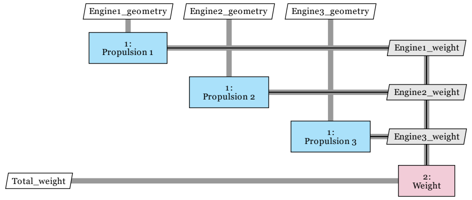


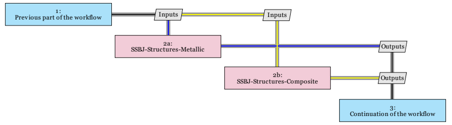


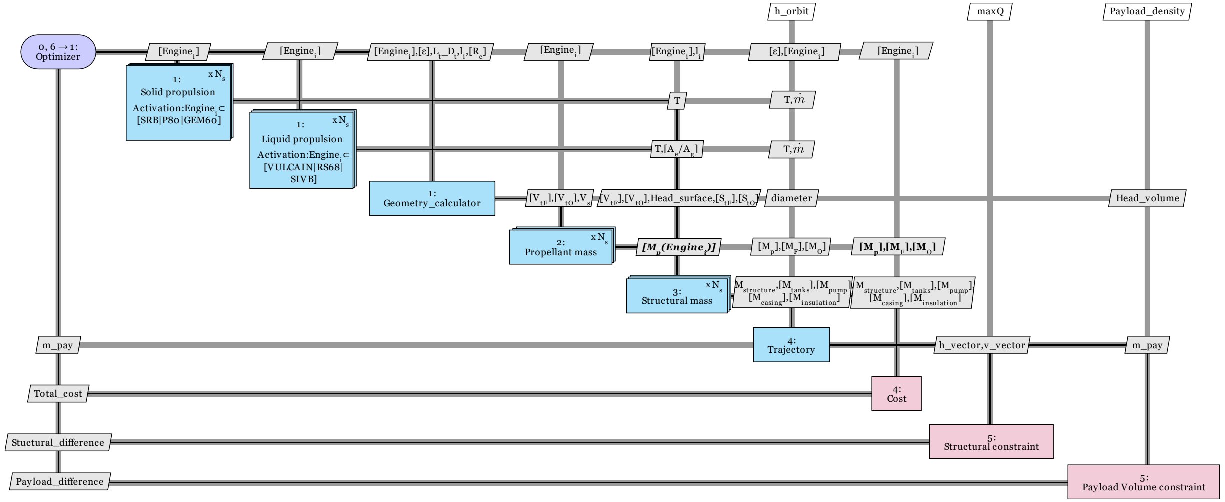


Conclusions & Outlook









- MDAO is essential for SAO
- 4 architectural influences
  - Discipline activation & repetition
  - Data connection & conditional variables
- Implementation in MDAx and RCE
- Demonstration: launch vehicle
  - Various architectural choices
  - Dynamic XDSM
- Future work
  - Implement dynamic MDAO in MDAx GUI
  - Various improvements to RCE export
  - Define process to co-develop system architecture and MDAO capabilities

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References

- Garg, Sparsh & Sánchez, Raúl & Bussemaker, Jasper & Boggero, Luca & Nagel, Björn. (2024). Dynamic Formulation and Execution of MDAO Workflows for Architecture Optimization. 10.2514/6.2024-4402.
- Risueño, Andreas & Bussemaker, Jasper & Ciampa, Pier Davide & Nagel, Björn. (2020). MDAx: Agile Generation of Collaborative MDAO Workflows for Complex Systems. 10.2514/6.2020-3133.
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- Bussemaker, J.H., Boggero, L. and Nagel, B., 2024, July. System Architecture Design Space Exploration: Integration with Computational Environments and Efficient Optimization. In AIAA Aviation 2024 Forum. DOI: 10.2514/6.2024-4647