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hybrid event

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From System Architecting to System Design and Optimization: *A Link Between MBSE and MDAO*

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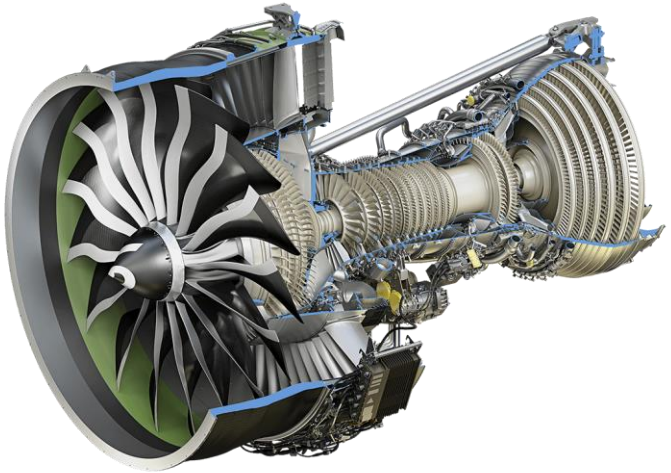
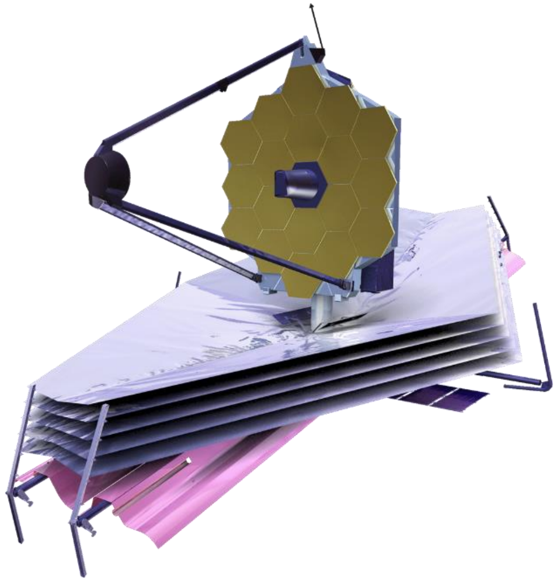
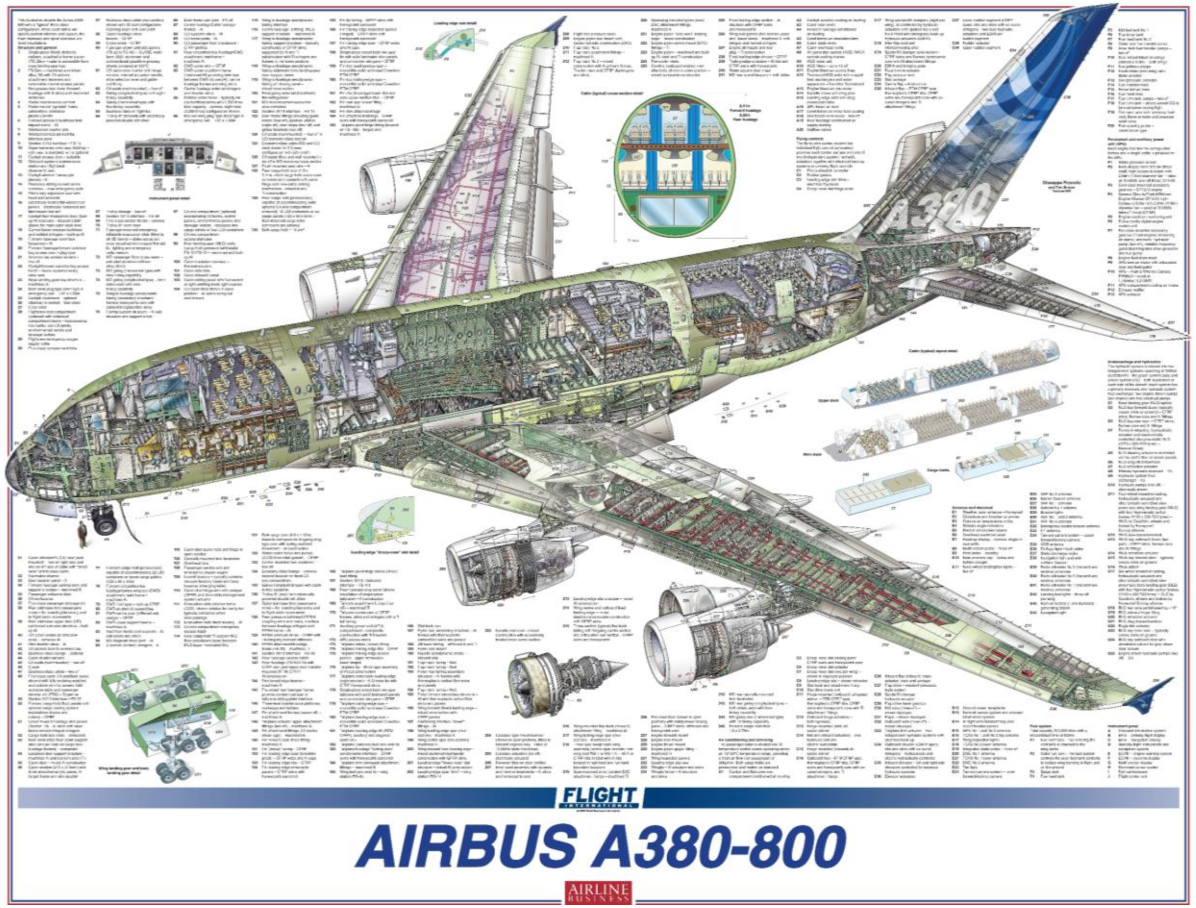
AGILE 4.0

Systems Engineering

- Designing successful systems
- Big picture approach
- Interdisciplinary



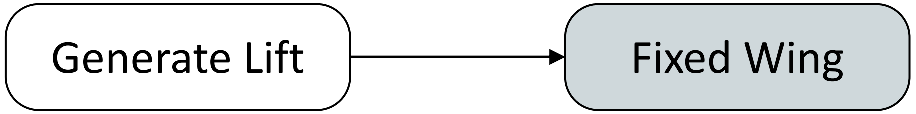


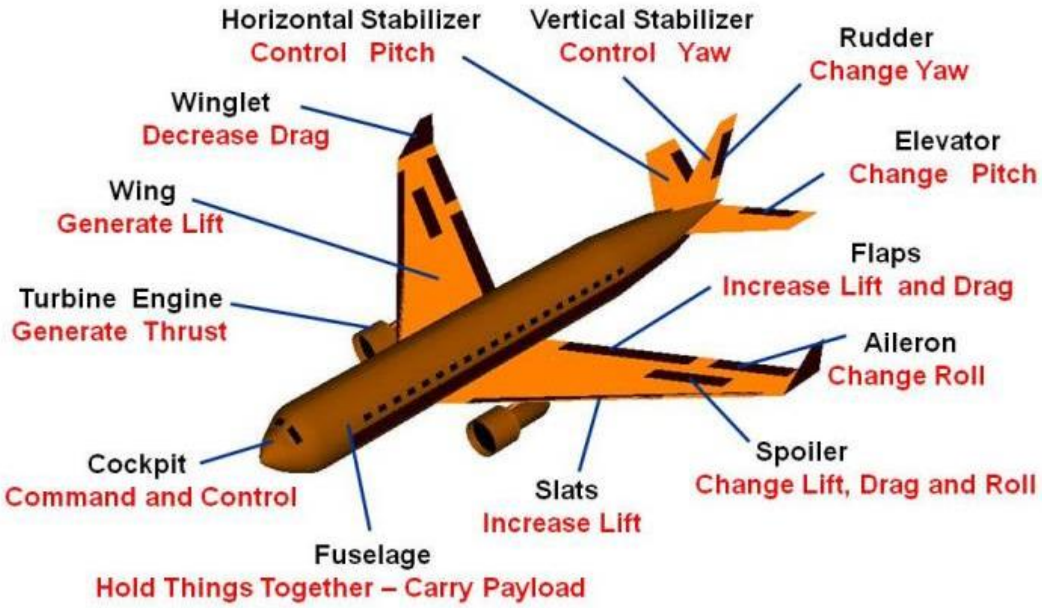


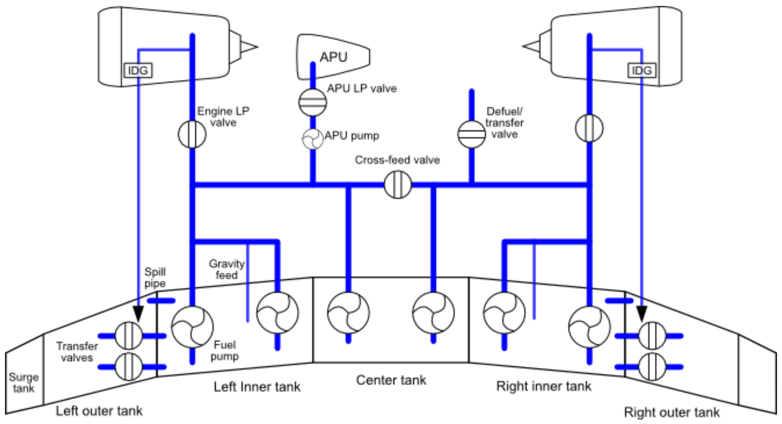
INCOSE, "Systems Engineering Handbook v3", 2006

System Architecture Describes a System

- From problem to solution
- Allocation of function to components
- Relationships among components
- Great influence on system performance

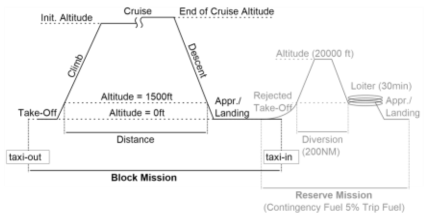


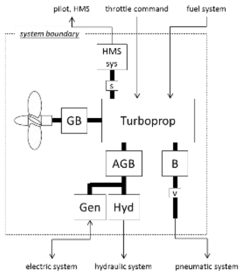


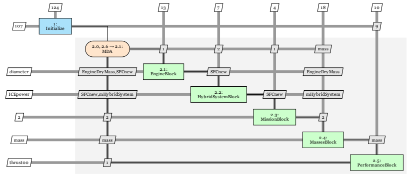


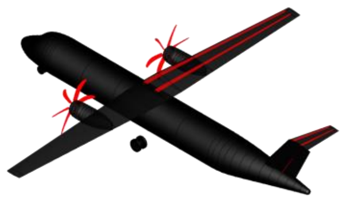
E. Crawley, B. Cameron, and D. Selva, “System Architecture: Strategy and Product Development for Complex Systems”, Harlow (UK), 2016

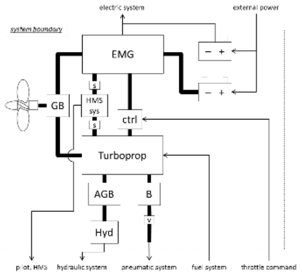
System Architecting: A Decision-Making Process

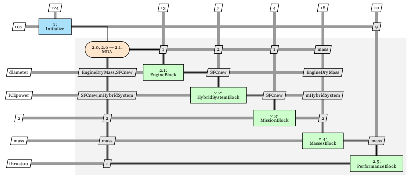


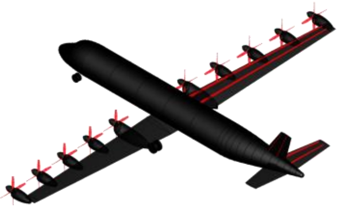


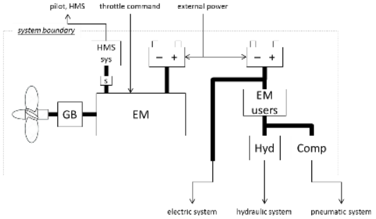


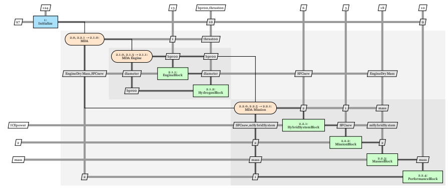


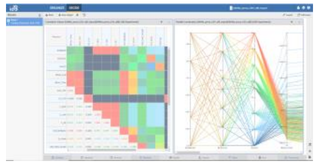












Requirements

Identify decisions;
Define architectures

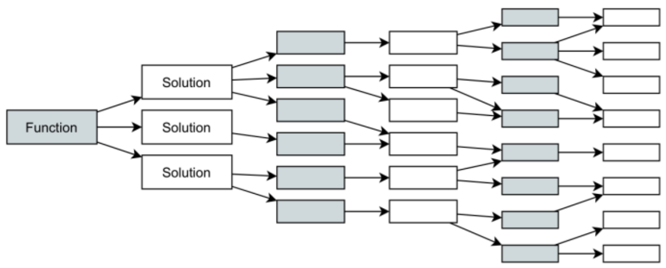
Analyze

Compare

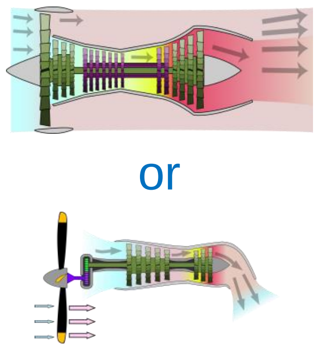
Some Architecture Decision Patterns

Combining

Discrete set of mutually-exclusive options



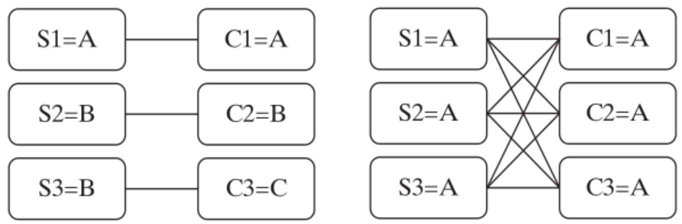
Provide thrust

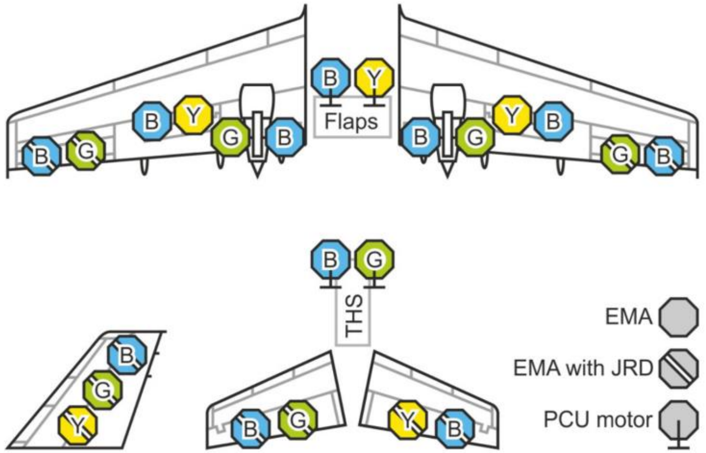


or

Assigning

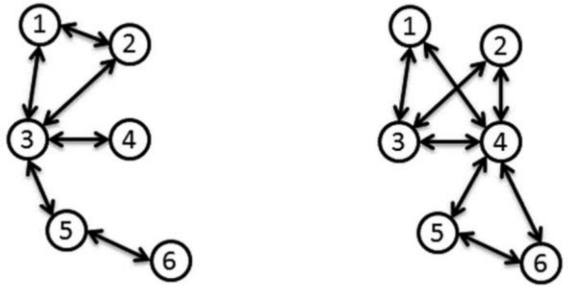
Assigning entries of one set to another

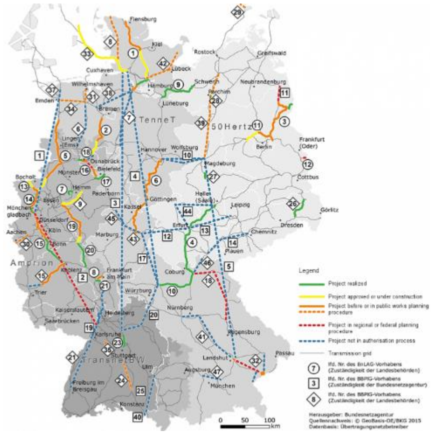




Connecting

Connecting nodes in a network





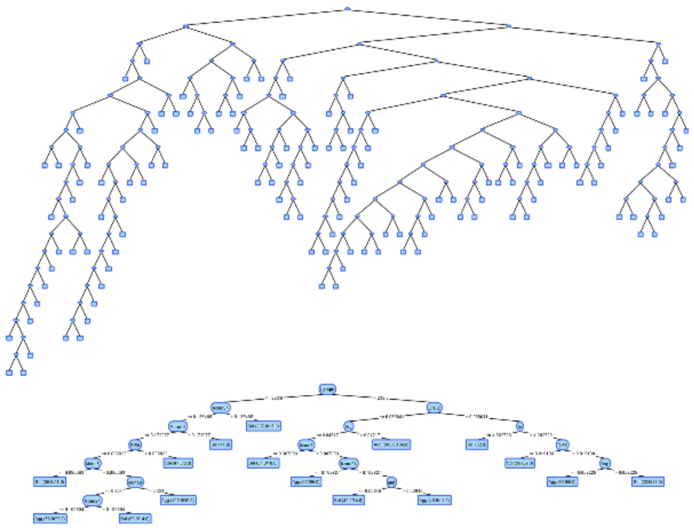
D. Selva, B. Cameron, and E. Crawley, “Patterns in System Architecture Decisions”, Systems Engineering, 2016

Some Architecture Decision Patterns

Combining **Assigning** **Connecting**

The problem?

A combinatorial explosion of alternatives!



Restrict options based on experience?
- Subject to bias
- Difficult to find novel architectures

Solution: *architecture optimization*
- Automatically generate architectures
- Quantitative performance evaluation

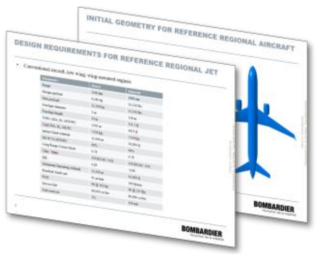
PCU motor

D. Selva, B. Cameron, and E. Crawley, "Patterns in System Architecture Decisions", Systems Engineering, 2016

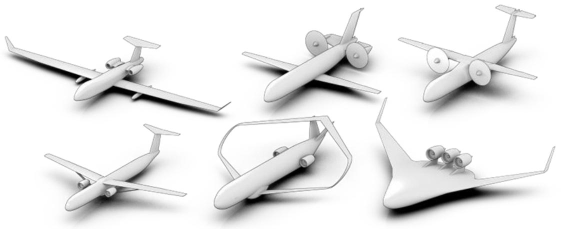
AGILE4.0 Framework for Development of Complex Systems

given policy & needs	*given goals & capabilities*	*given scenarios & requirements*	*given architecture & requirements*	*given design space & objectives*
System Identification	**System Specification**	**System Architecting**	**System Synthesis**	**System Exploration**

Capabilities & Objectives

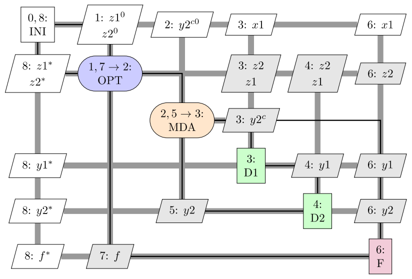


Requirements & ConOps



Architecture Alternatives

Integration & Validation



Design and Optimization

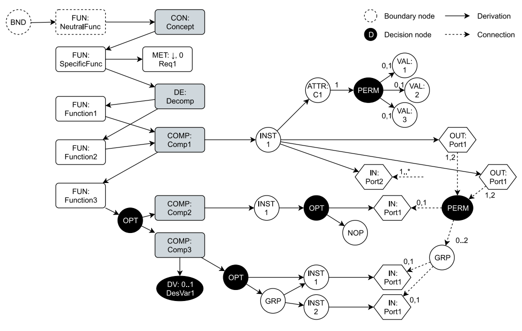
upstream architecting SE (document or model based)

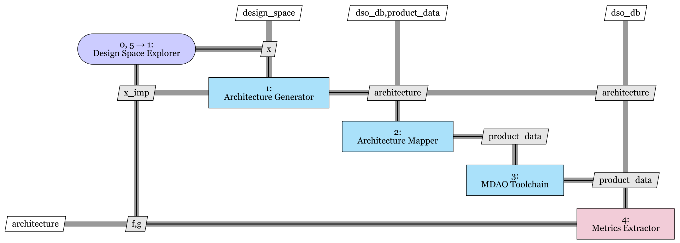
INCOSE Handbook, NASA SE Handbook
ISO/IEC 15288, ISO/IEC 42010, DoDAF, ToGAF, UAF

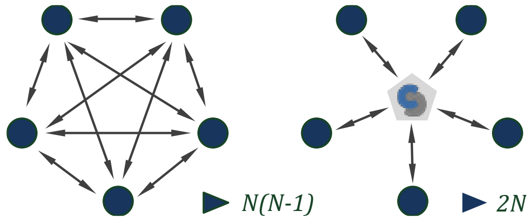
downstream product design MDAO

P.D. Ciampa, B.Nagel, "Accelerating the Development of Complex Systems in Aeronautics via MBSE and MDAO: a Roadmap to Agility", AIAA AVIATION 2021

Presentation Outline







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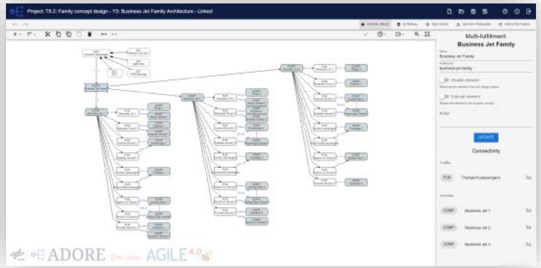
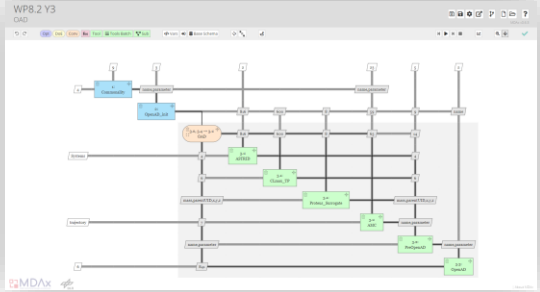


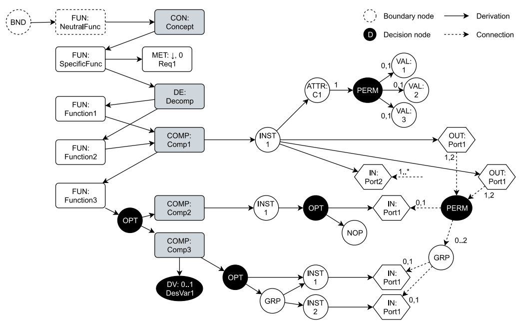
MULTILINQ

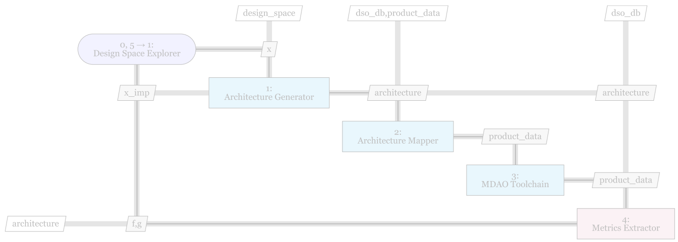
MDAx
MDO Workflow Design Accelerator



DLR AGILE 4.0

Architecture Design Space Modeling





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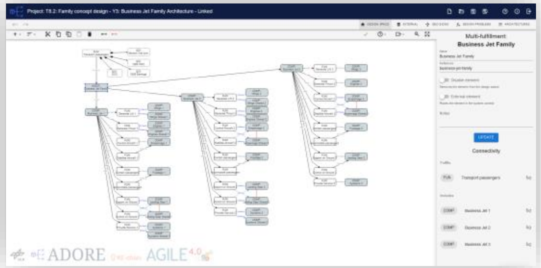

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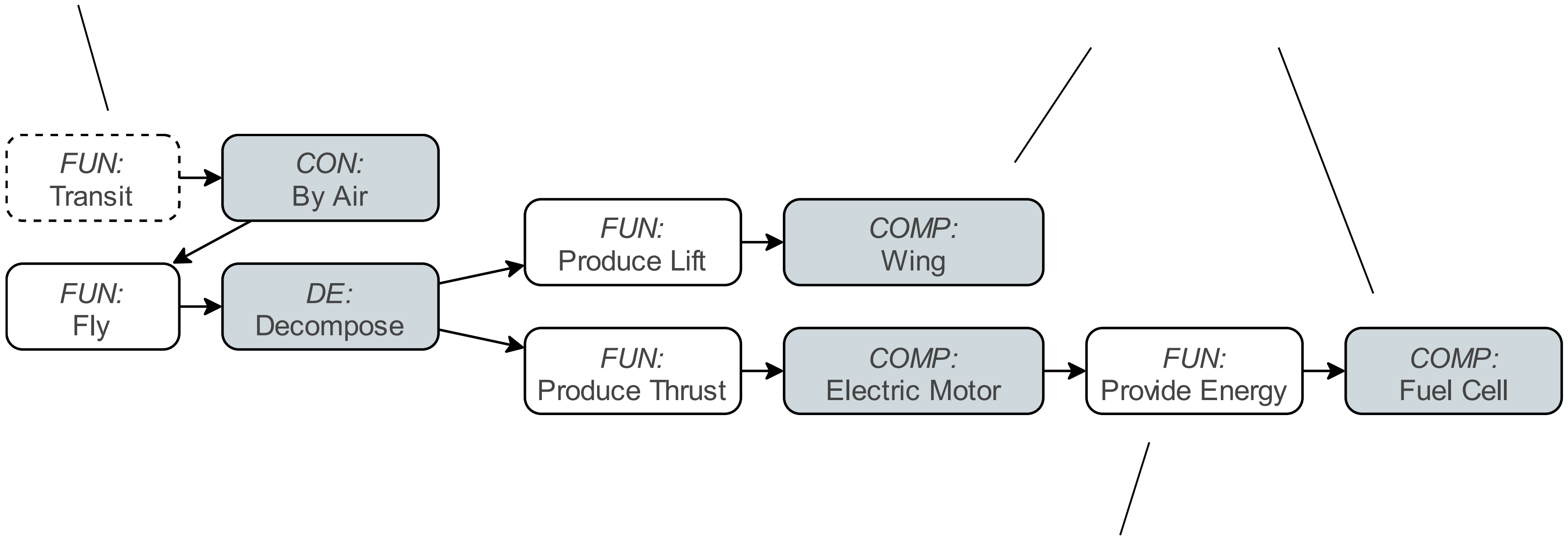
MDAx
MDO Workflow Design Accelerator

Function-Based Architecting

Boundary functions
from system requirements

Components ***fulfill*** **functions**



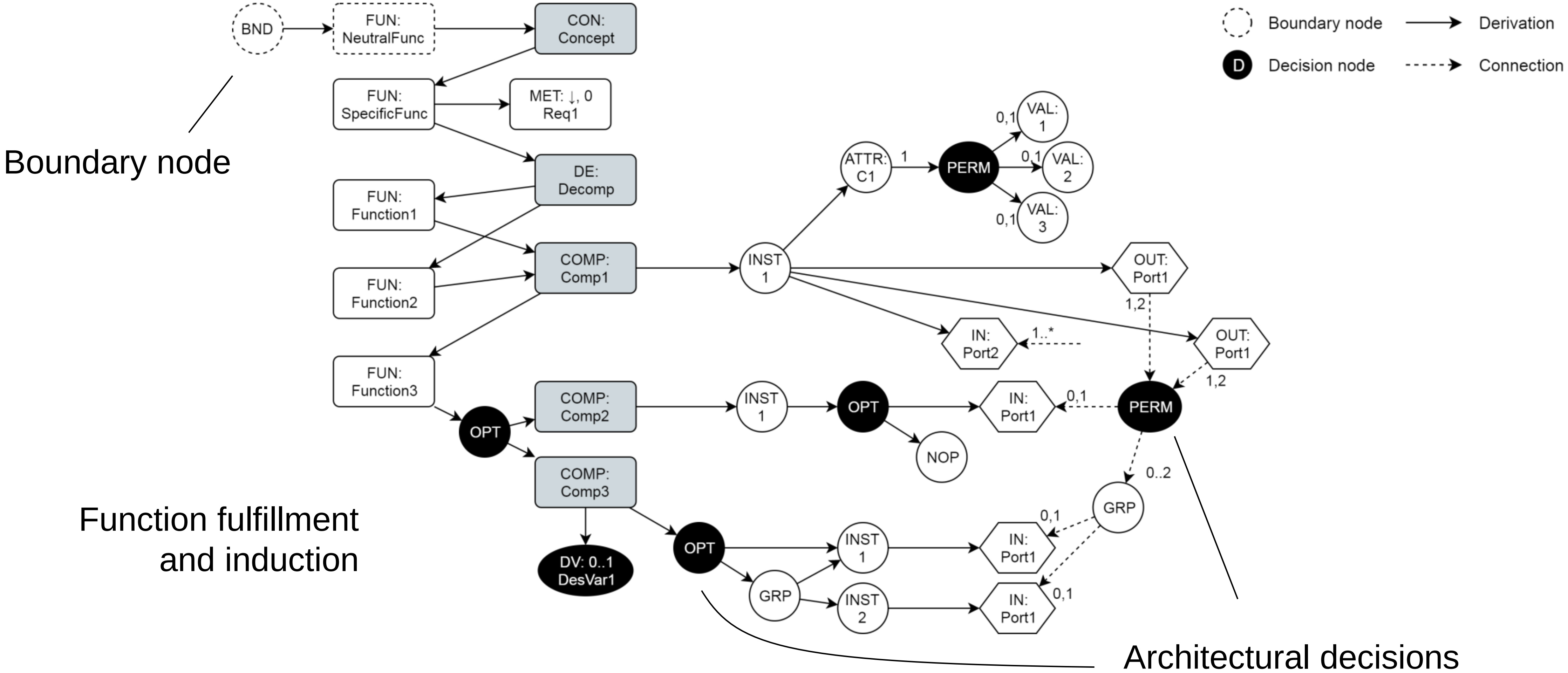
Components can *induce* additional functions

Some benefits:

- Natural transition from problem to solution
- Less prone to solution bias
- Directly traceable to requirements

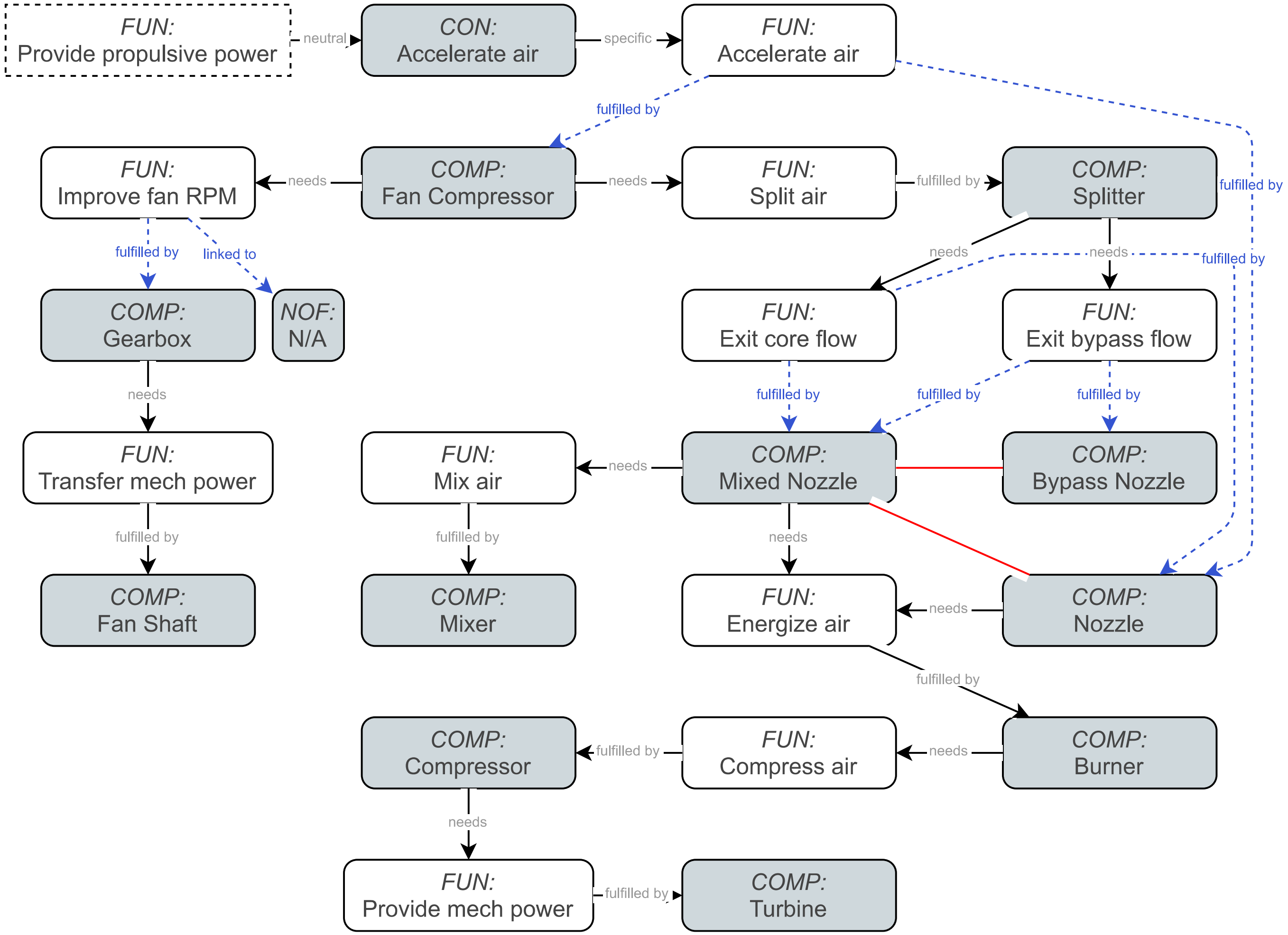
J.H. Bussemaker, P.D. Ciampa, and B. Nagel, "System architecture design space exploration: An approach to modeling and optimization", AIAA AVIATION 2020

Architecture Design Space Graph (ADSG)



J.H. Bussemaker, P.D. Ciampa, and B. Nagel, "System architecture design space exploration: An approach to modeling and optimization", AIAA AVIATION 2020

Example Architecture Design Space

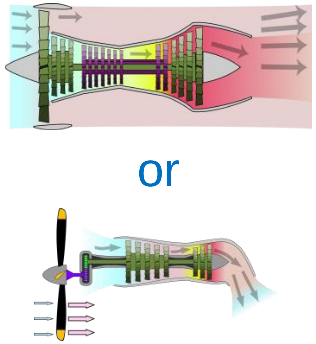


Types of Architectural Decisions

Fulfilling Functions

- Which component fulfills which function?

Provide thrust



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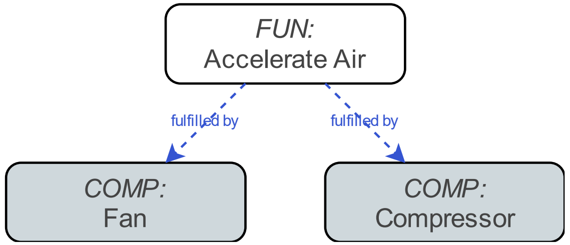
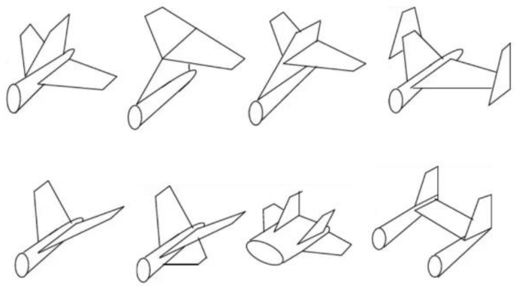
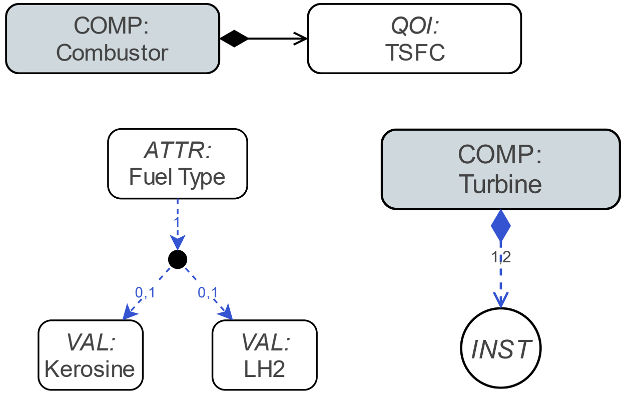


Characterization

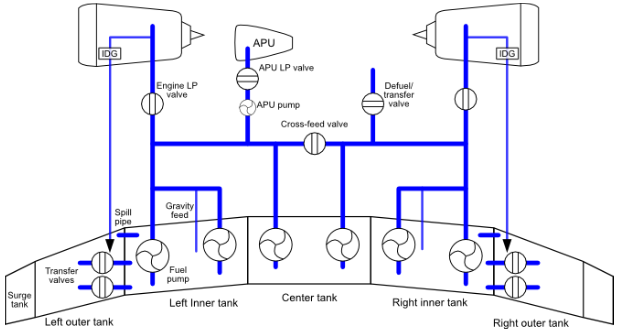
- Number of instances
- Property values

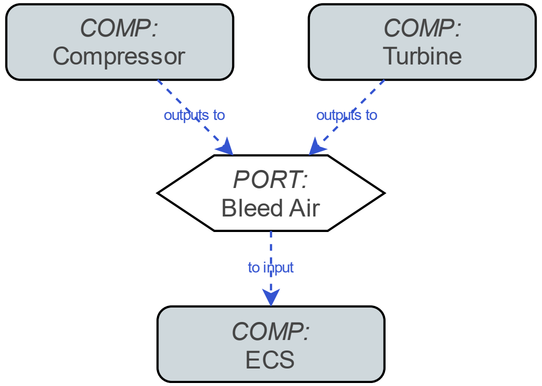




Connections

- Connect output to input ports
- Permutation problem



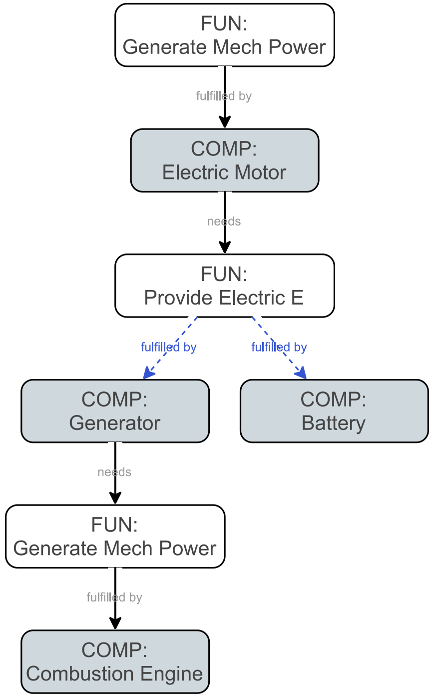


DLR AGILE 4.0

Architectural Decisions to Architecture Instances

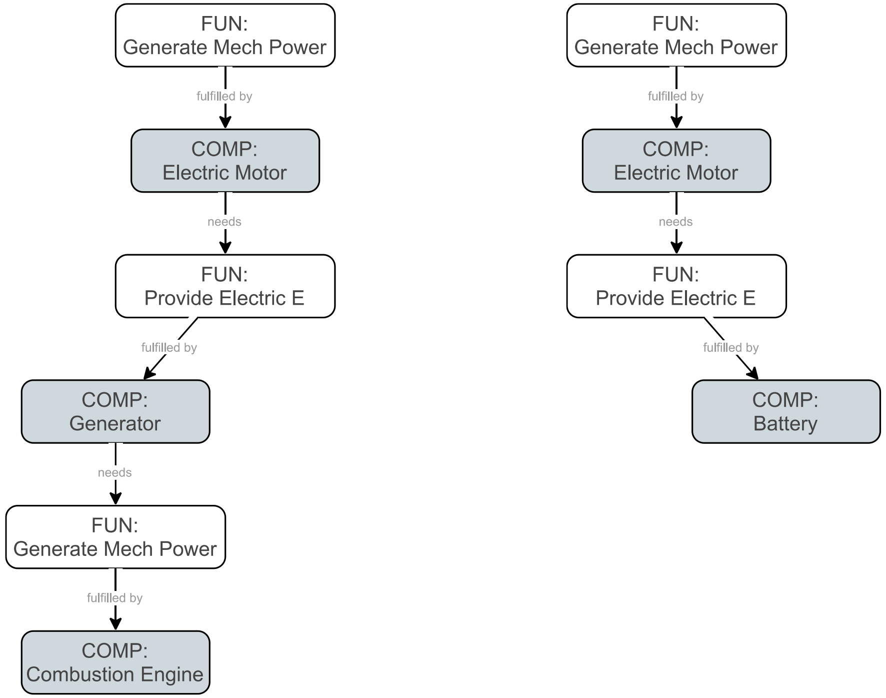
Architecture Design Space

- One model describing all possible architectures
- Contains decisions



Architecture Instances

- Specific architectures
- All decisions have "options" assigned
- Can be evaluated / analyzed



ADSG Implementation and Editor

Architecture **design space** modeler

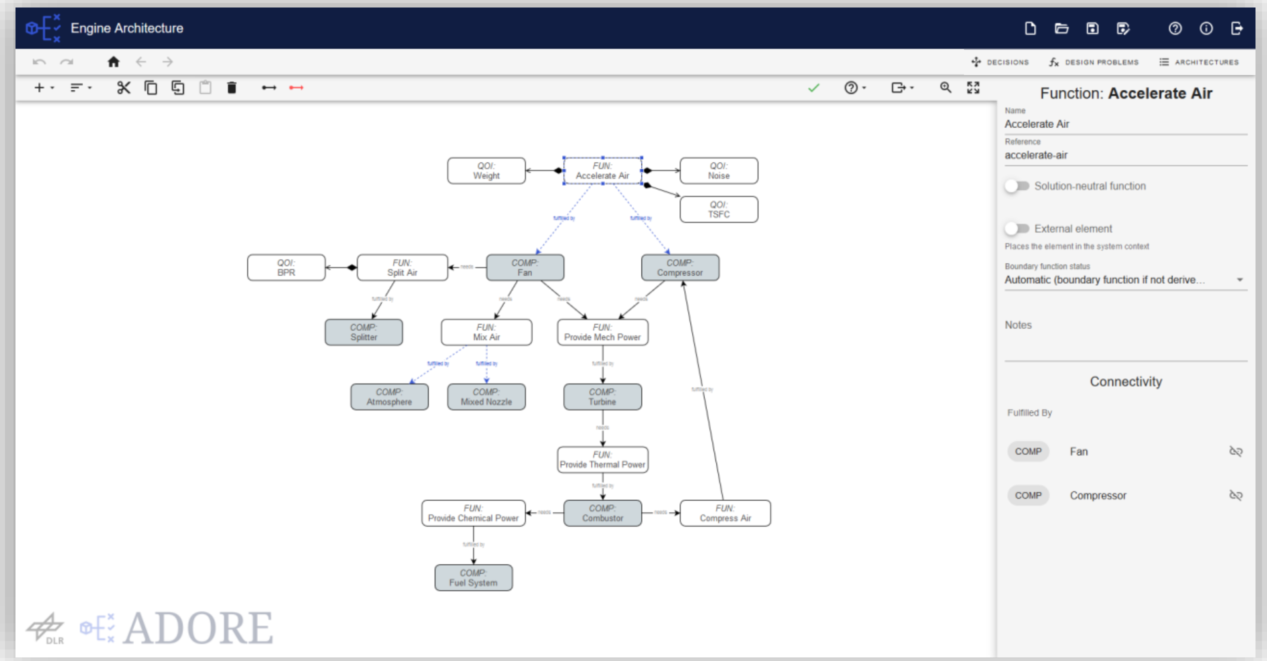
- Define functions, components, connections
- Identify architectural decisions
- Define Quantities of Interest (QOIs)

Architecture **generator**

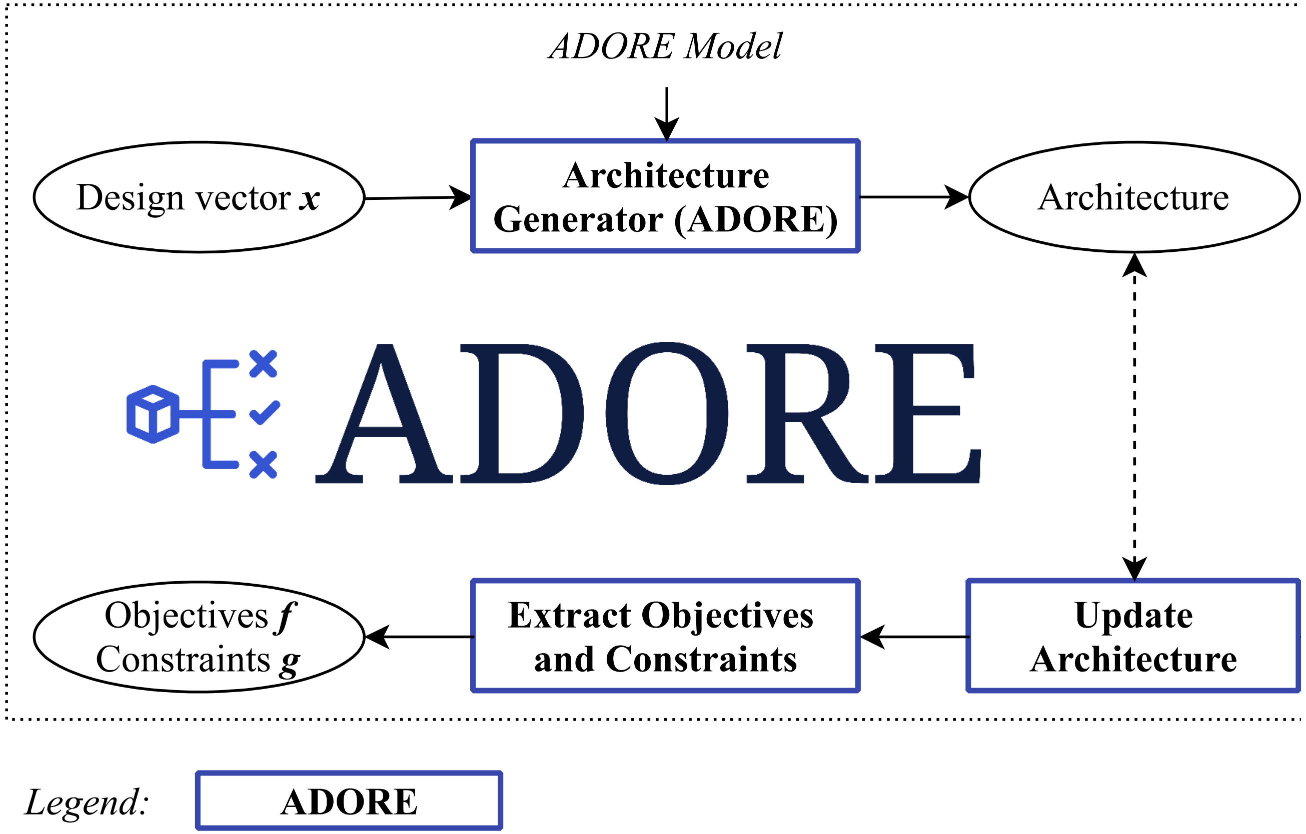
- Create architectures by assigning options
- Connect to evaluation environment

Architecture **optimization** framework

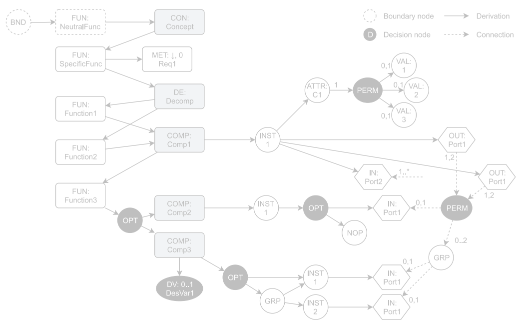
- Define design variables, objectives, constraints
- Connect to optimization libraries

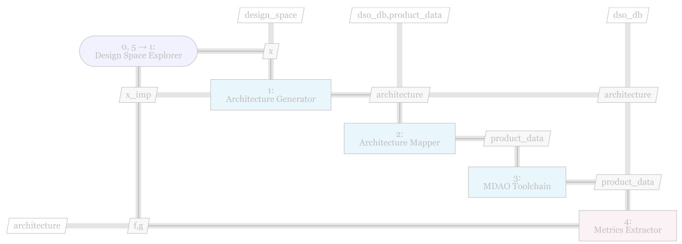


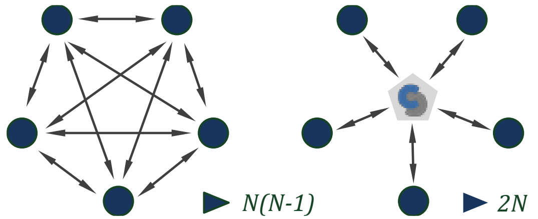
Architecture Optimization Loop (33%)



Collaborative MDAO







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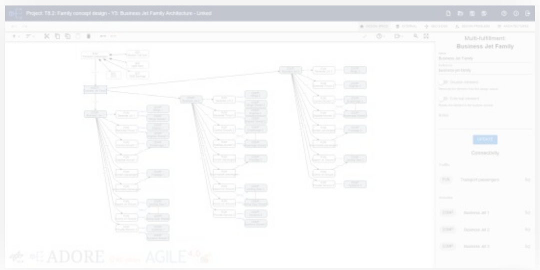
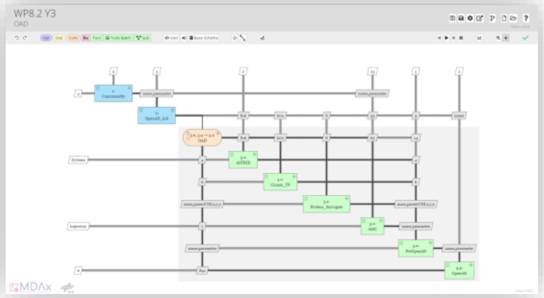


MULTILINQ

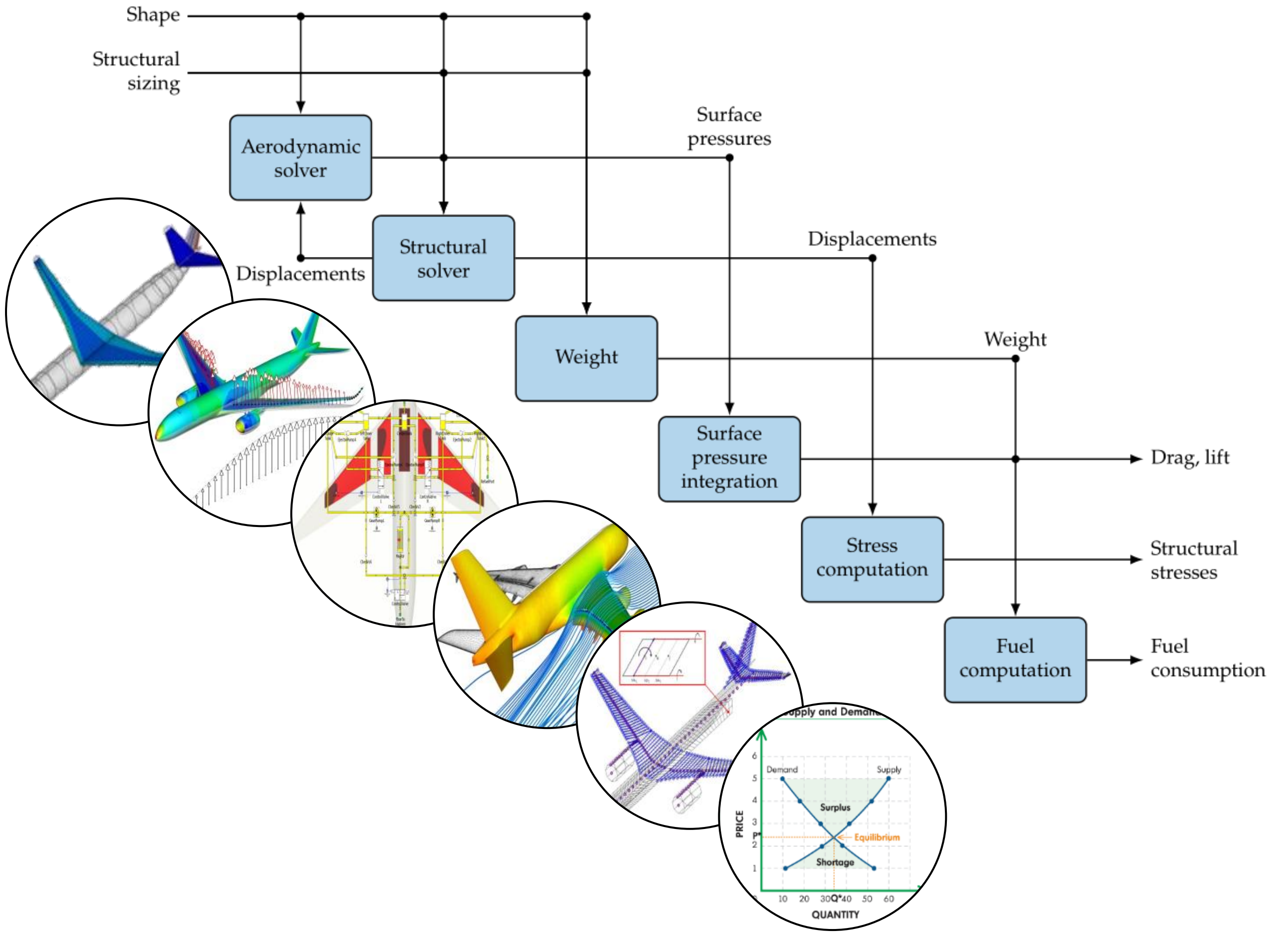
MDAx
MDO Workflow Design Accelerator



DLR AGILE 4.0

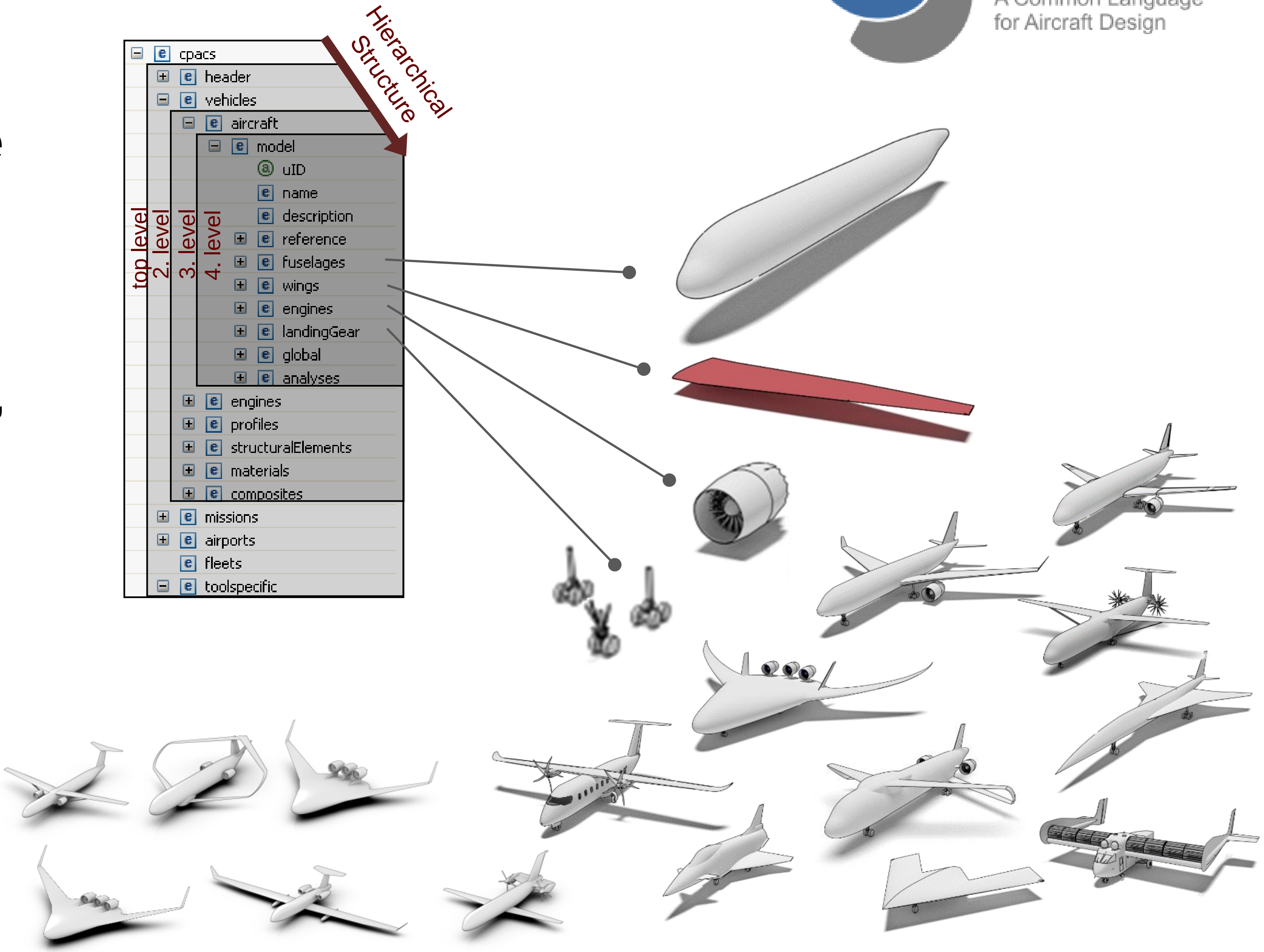
Multidisciplinary Design Analysis & Optimization

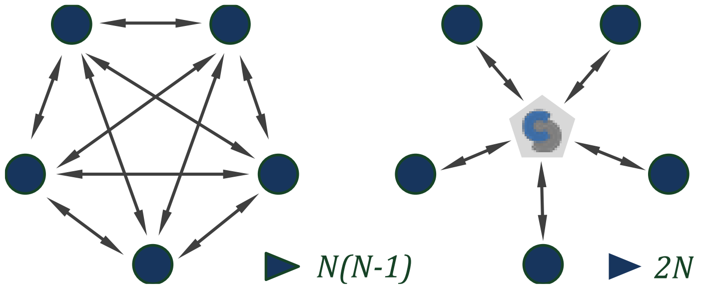
- Different elements influence system performance differently
- Different engineering disciplines with different design goals
- MDAO enables numerical connection of disciplines
- How to communicate data between heterogeneous/distributed tools?



Collaborative MDAO using CPACS

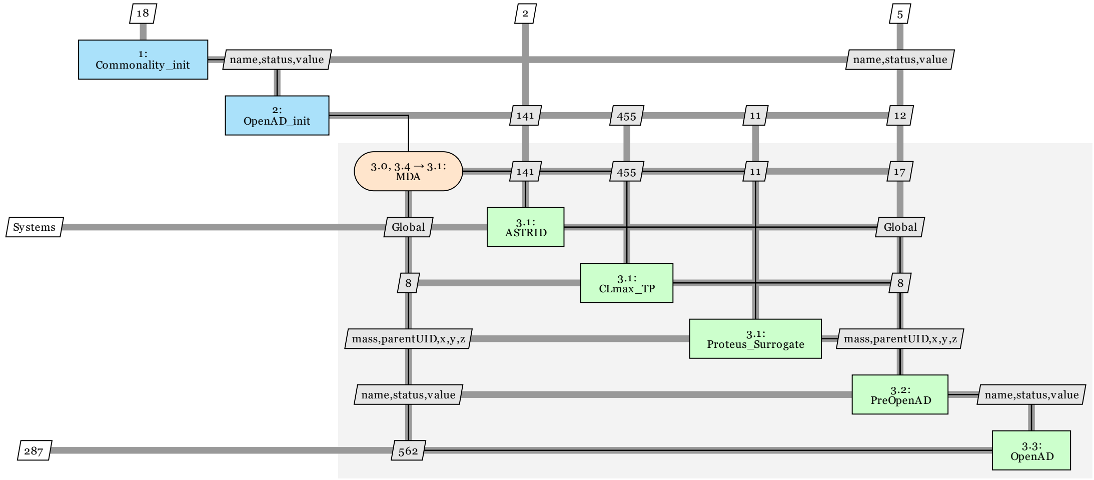
- XML-based aircraft data storage
- Applied in many projects
- Many analysis tools that “speak” CPACS





MDAO Workflow Modeling

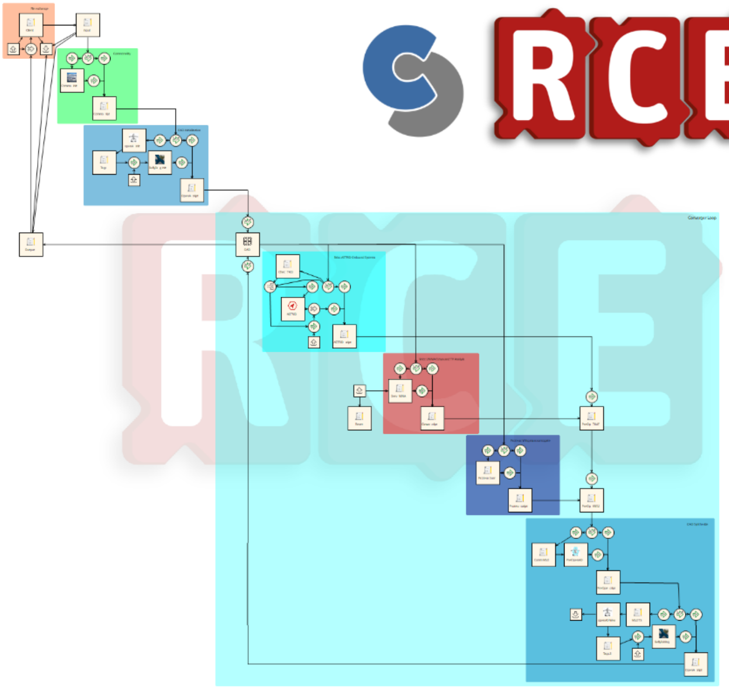
Modeling the workflow from tool I/O definitions



MDAx
MDO Workflow Design Accelerator

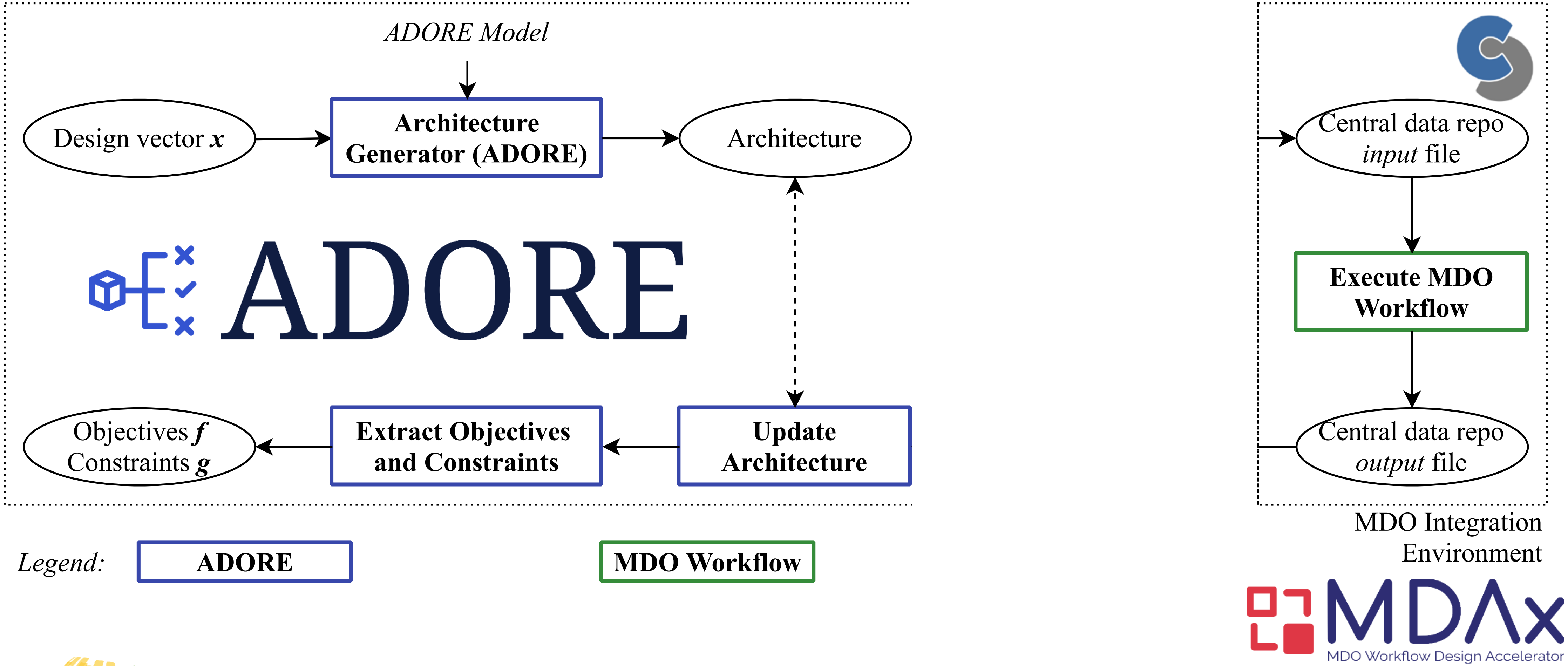
To support workflow implementation

RCE

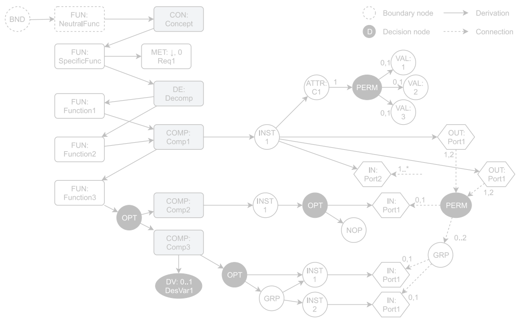


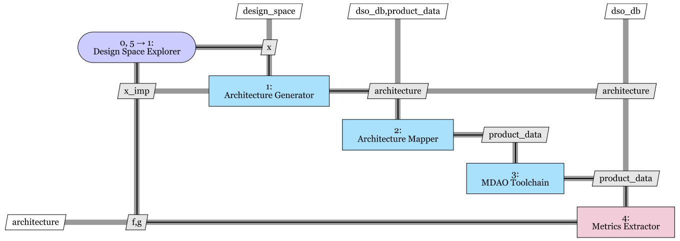
- Connections automatically discovered
- Correct I/O filtering
- Easier to make changes

Architecture Optimization Loop (66%)



Connecting Architecting and Collaborative MDAO





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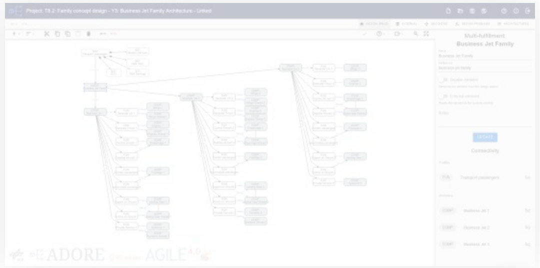


MULTILINQ

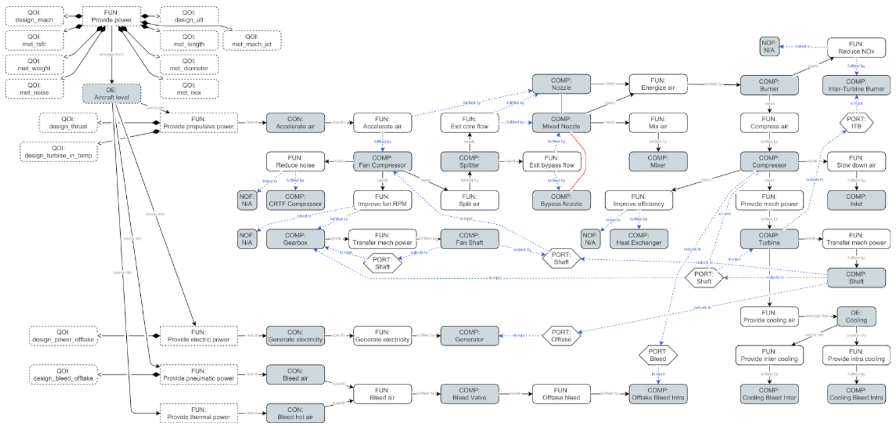
MDAx
MDO Workflow Design Accelerator

DLR AGILE 4.0

Different Worlds: MBSE and MDAO

MBSE Architecture Model

- Logical description of the SOI
- Described in terms of functions, components, QOIs, etc.
- Link to upstream requirements



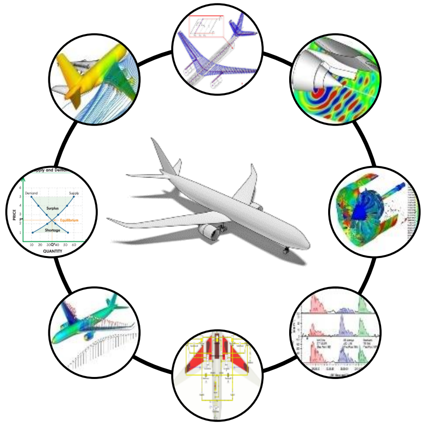
Verify Disciplines

Sync Architecture

Performance Data

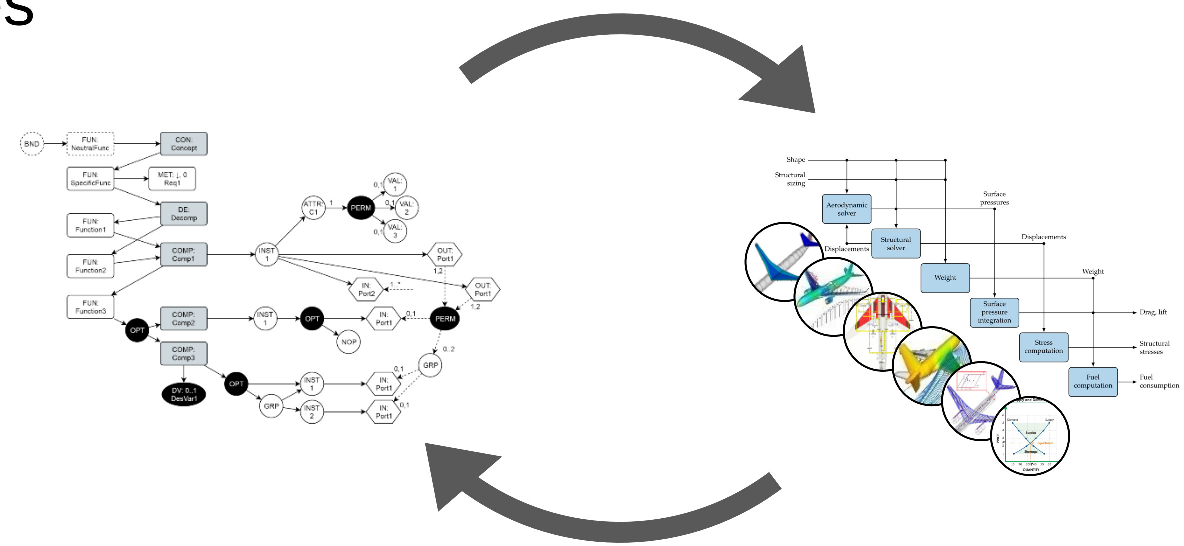
MDAO Product Model

- Physical description of the SOI
- Described using CPACS, in terms of geometry, performance data, etc.
- Connected to disciplinary tools



How to Synchronize Architectures with a Central Data Schema?

- Associate elements to data schema nodes
- **Data Schema Operations (DSO's)**



Architecture-to-MDO connection

- **Synchronize** architecture with data schema
- Automatically **copy nodes** according to the number of component instances

MDO-to-architecture connection

- **Extract** performance data
- Close the evaluation loop


```
<mWingsStructure>
    <massDescription uID="mWingsStructure">
        <mass>1672.3220548910942</mass>
    </massDescription>
    <mWingStructure>
        <massDescription uID="wing_mass">
            <parentUID>wing</parentUID>
            <mass>1229.6052745879338</mass>
```


→ **DSO** "Read value" → *QOI:* Wing Weight: 1229.61

Available Data Schema Operations

Element	0 instances	1 instance	2+ instances
QOI (input)	Write empty value; Remove node; Do nothing	Write value to node	Write list of values; Write to copied nodes

Available Data Schema Operations

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QOI (input)	Write empty value; Remove node; Do nothing	Write value to node	Write list of values; Write to copied nodes
QOI (output)	Assign NaN	Read value from node	Read from list; Read from copied nodes

Available Data Schema Operations

Element	0 instances	1 instance	2+ instances
QOI (input)	Write empty value; Remove node; Do nothing	Write value to node	Write list of values; Write to copied nodes
QOI (output)	Assign NaN	Read value from node	Read from list; Read from copied nodes
Component	Remove node; Do nothing; Write nr of instances	Create new node; Write nr of instances	Copy (new) node; Write nr of instances

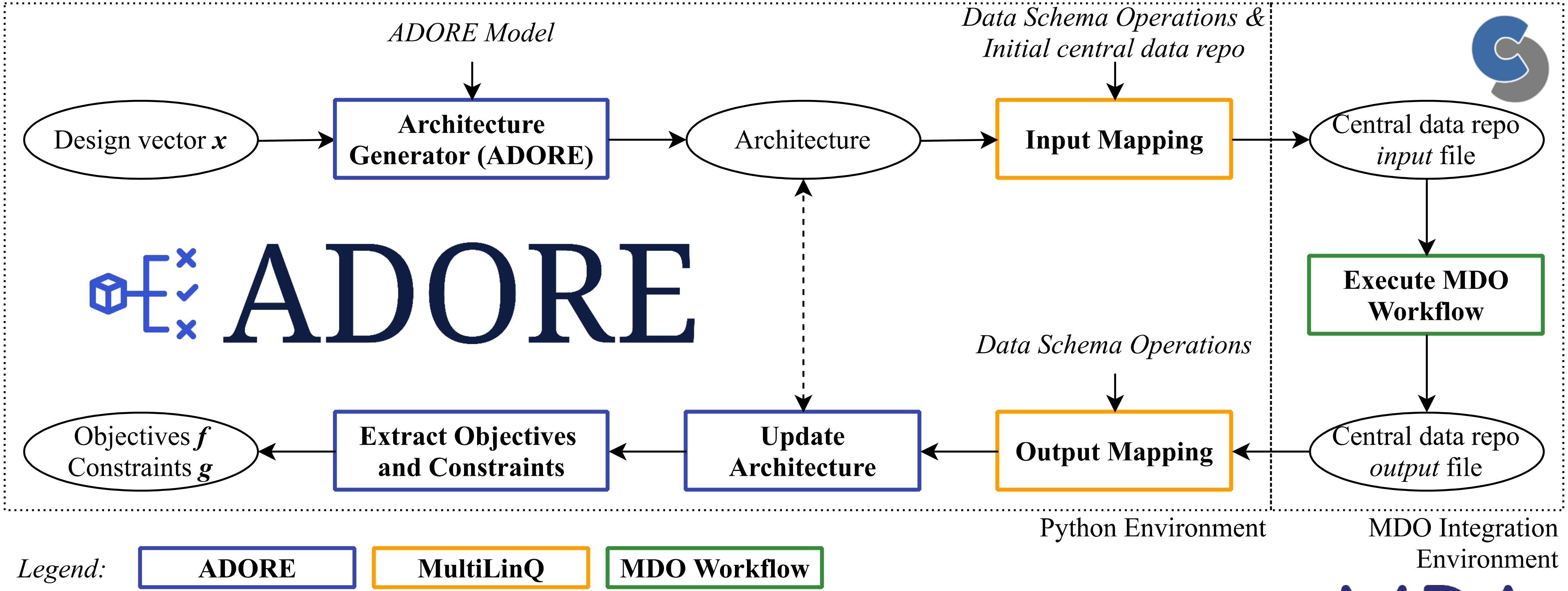
Supporting MDO Tool Selection

The *Component-Tool Matrix:*

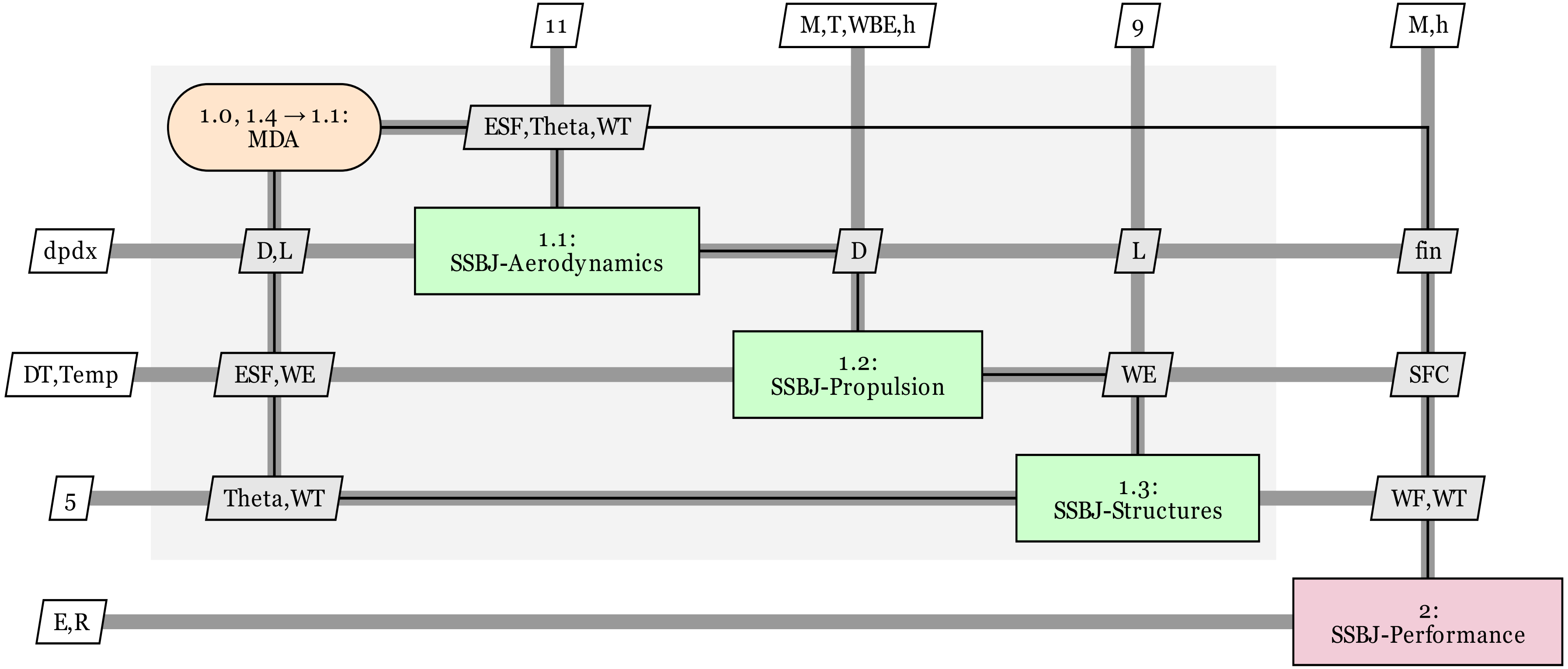
- **Verify** selected tools cover architecture components
- Identify **redundant** tools
- Identify **missing** tools
- Identify **unnecessary** tools

		Tools				
Components	**QOIs**	Aerodynamics	Cost	Performance	Propulsion	Structures
Engines	Base engine weight				✓	
Engines	Thrust				✓	
Fuel system	Fuel price					
Fuel system	Misc fuel weight					✓
Wings	AR	✓				✓
Wings	Reference area	✓				✓
Wings	Sweep	✓				✓
Wings	Taper ratio					✓
Wings	t/c	✓				✓
Wings structure	Load factor					✓
Wings structure	x					✓
	Altitude	✓		✓	✓	

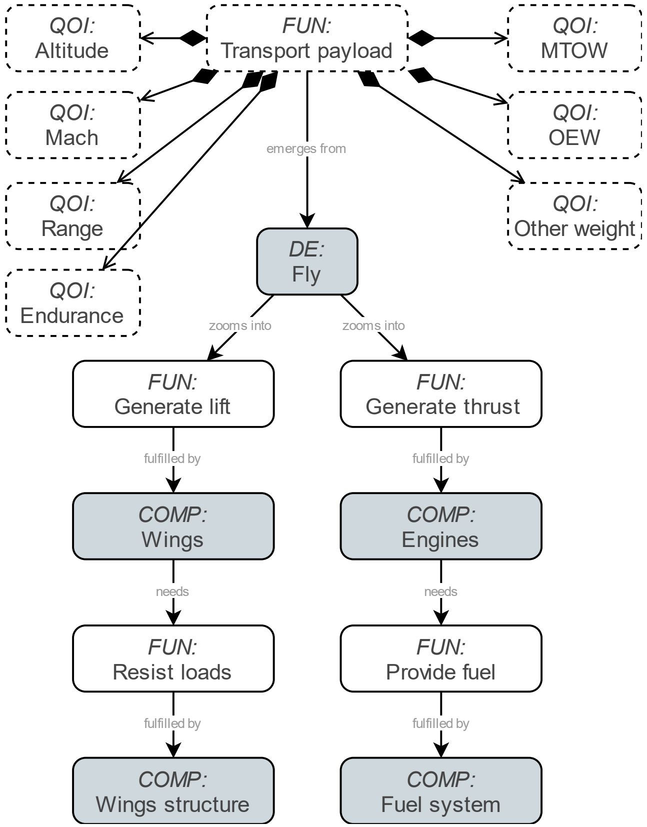
Architecture Optimization Loop (100%)

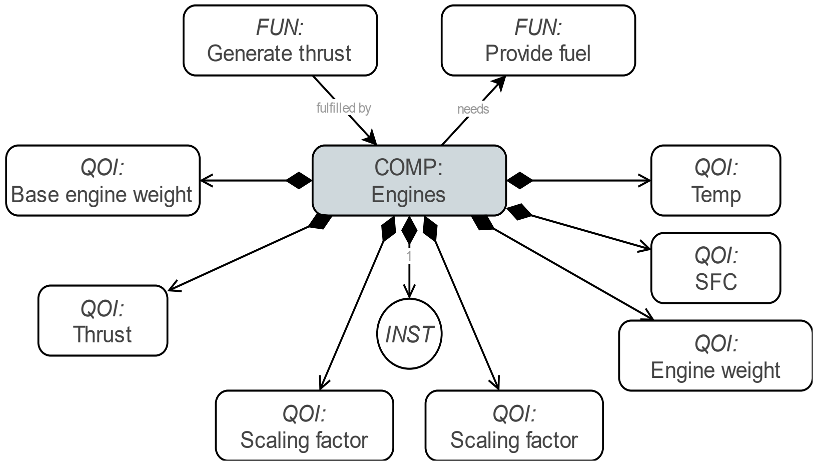


Demonstration: SSBJ MDAO Workflow Model



Demonstration: SSBJ Architecture Model

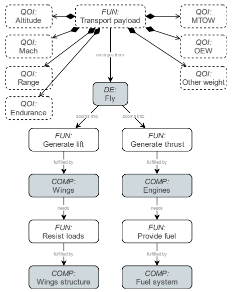


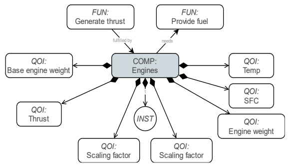


Demonstration: SSBJ Component-Tool Matrix

		Tools			
Components	**QOIs**	SSBJ-Aerodynamics	SSBJ-Performance	SSBJ-Propulsion	SSBJ-Structures
Engines	Base engine weight			✓	
Engines	Thrust			✓	
Fuel system	Misc fuel weight				✓
Wings	AR	✓			✓
Wings	Reference area	✓			✓
Wings	Sweep	✓			✓
Wings	Taper ratio				✓
Wings	t/c	✓			✓
Wings structure	Load factor				✓
Wings structure	x				✓
	Altitude	✓	✓	✓	
	Mach	✓	✓	✓	
	Other weight				✓
Engines	Engine weight			✓	
Engines	SFC			✓	
Engines	Scaling factor			✓	
Engines	Scaling factor			✓	
Engines	Temp			✓	
Fuel system	Fuel weight				✓
Wings	D	✓			
Wings	L	✓			
Wings	L/D	✓			
Wings	dpdx	✓			
Wings structure	Stress1				✓
Wings structure	Stress2				✓
Wings structure	Stress3				✓
Wings structure	Stress4				✓
Wings structure	Stress5				✓
Wings structure	Twist				✓
Wings structure	Twist				✓
	Endurance		✓		
	MTOW				✓
	OEW			✓	
	Range		✓		

Demonstration: SSBJ





Components	QOIs	Tools: SSBJ-Aerodynamics	SSBJ-Performance	SSBJ-Propulsion	SSBJ-Structures
Engines	Base engine weight			✓	
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Fuel system	Misc fuel weight				✓
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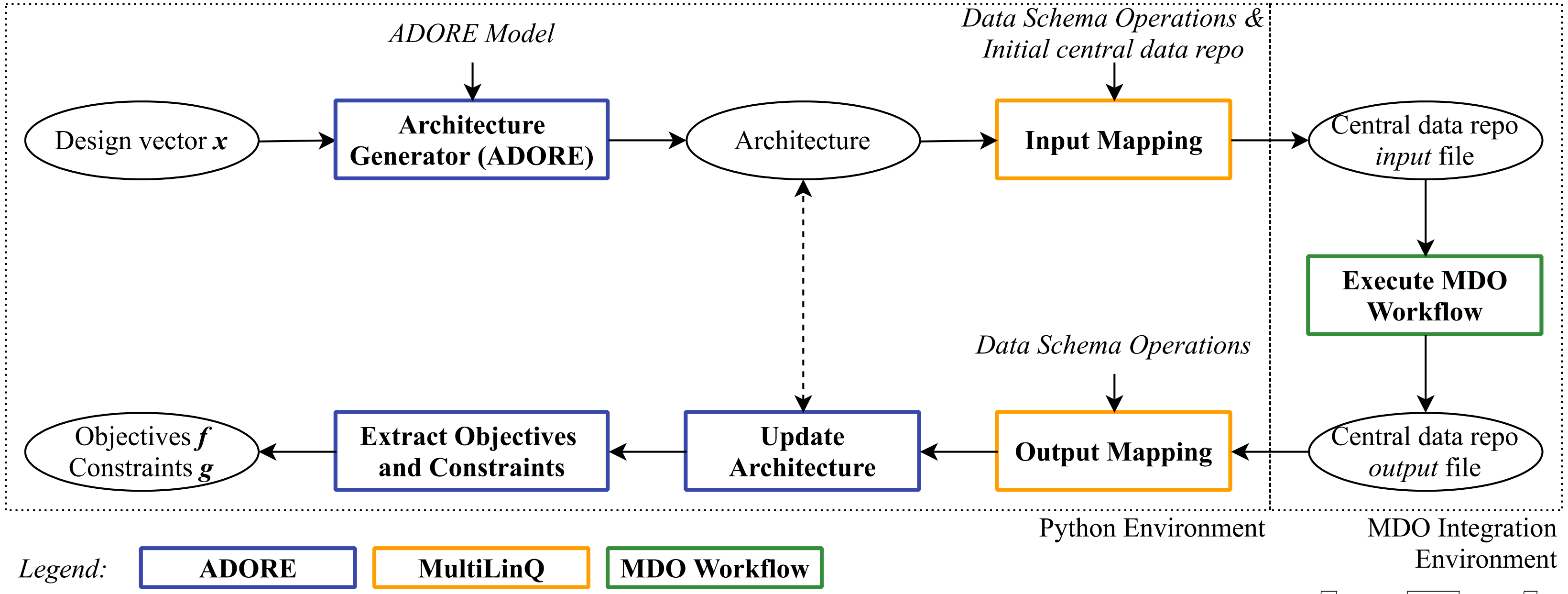
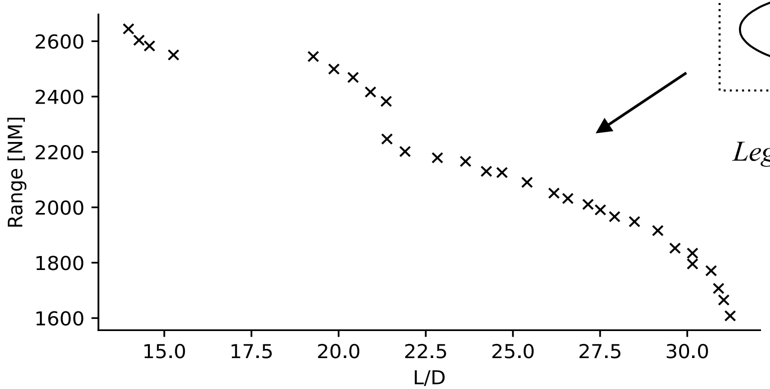
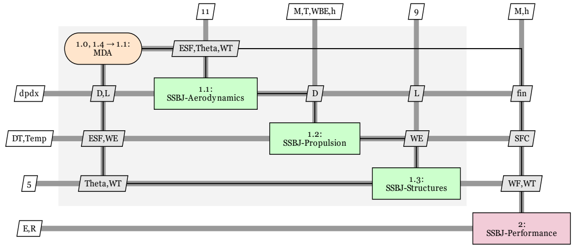
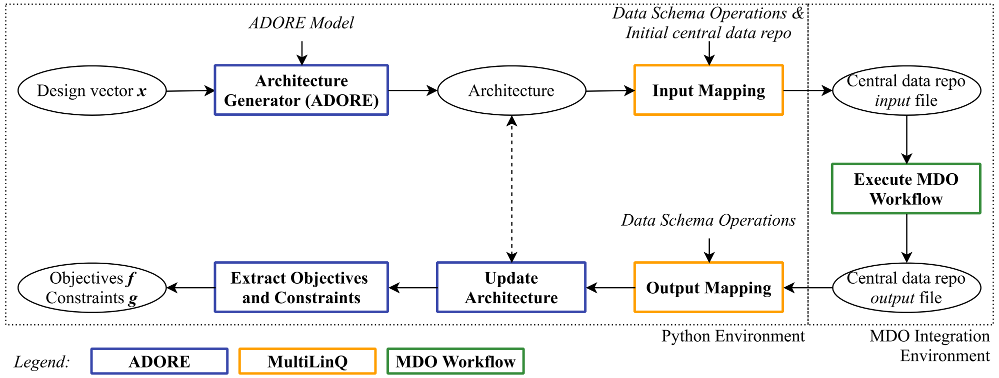
Wings	Reference area	✓			✓
Wings	Sweep	✓			✓
Wings	Taper ratio				✓
Wings	t/c	✓			✓
Wings structure	Load factor				✓
Wings structure	x				✓
	Altitude	✓	✓	✓	
	Mach	✓	✓	✓	
	Other weight				✓
Engines	Engine weight			✓	
Engines	SFC			✓	
Engines	Scaling factor			✓	
Engines	Scaling factor			✓	
Engines	Temp			✓	
Fuel system	Fuel weight				✓
Wings	D	✓			
Wings	L	✓			
Wings	L/D	✓			
Wings	dpdx	✓			
Wings structure	Stress1				✓
Wings structure	Stress2				✓
Wings structure	Stress3				✓
Wings structure	Stress4				✓
Wings structure	Stress5				✓
Wings structure	Twist				✓
Wings structure	Twist				✓
	Endurance		✓		
	MTOW				✓
	OEW			✓	
	Range		✓		





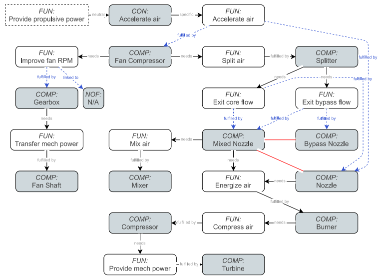


Conclusions and Outlook



Conclusions

- Architecture optimization methodology using
  - Architecture Design Space Graph (ADSG)
  - Collaborative MDAO
  - Data Schema Operations (DSOs) for linking
- Presented associated tools



		Tools				
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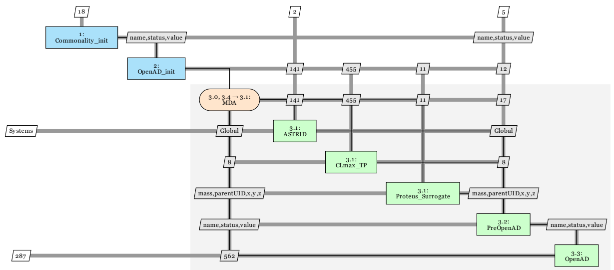
Wings	Taper ratio					✓
Wings	t/c	✓				✓
Wings structure	Load factor					✓
Wings structure	x					✓
	Altitude	✓		✓	✓	



Outlook

- Extend DSOs to support all architectural decisions
- Support dynamic MDAO workflows
- Test using industry-provided cases in AGILE4.0

AGILE 4.0

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