# Toward a front loaded design process

## MBSE-based methodologies to support KBE and MDAO

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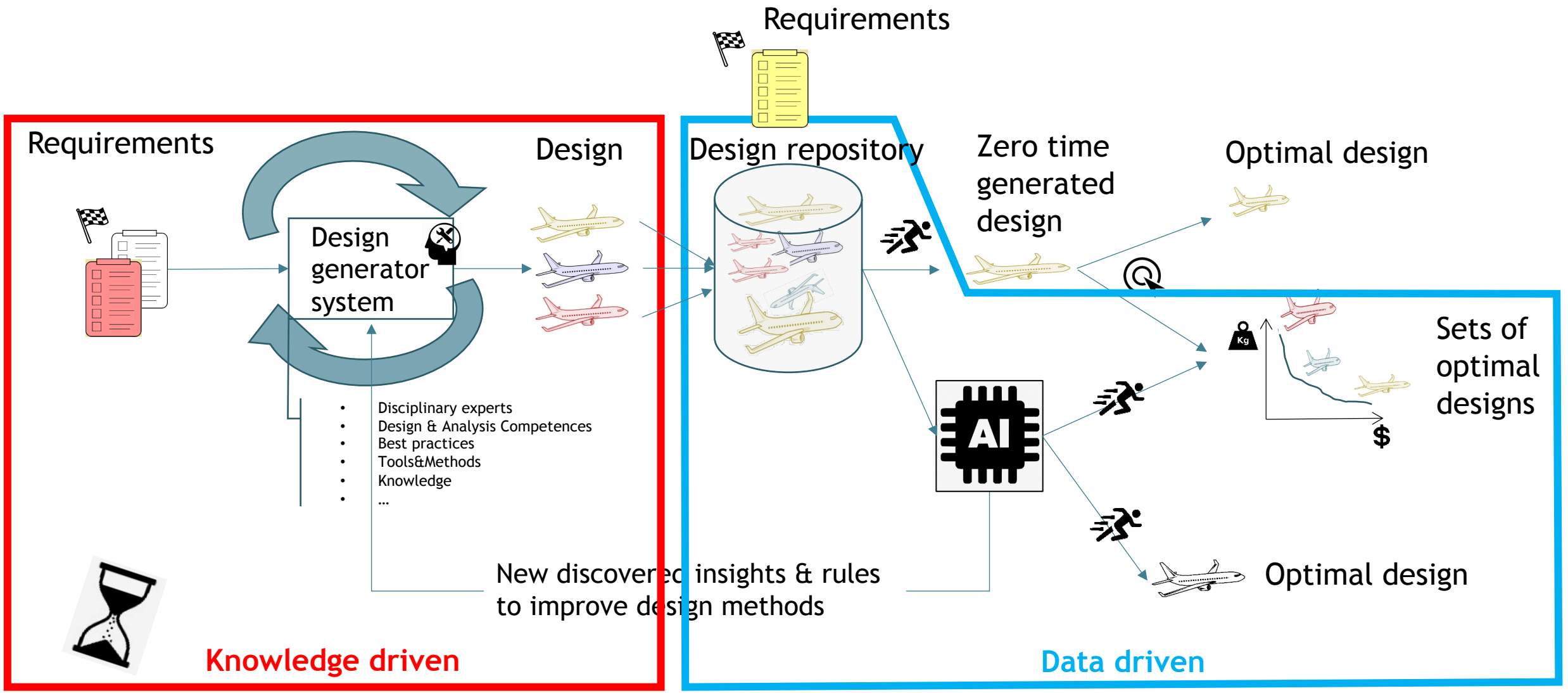
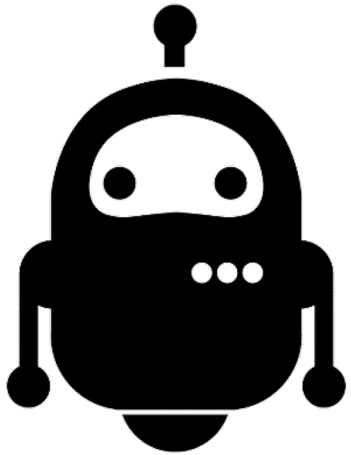
# Toward a front loaded design process



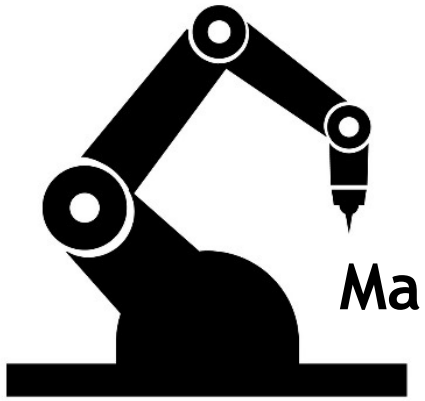
# Toward a front loaded design process

## The KBE (Knowledge Based Engineering) pillar



### Design

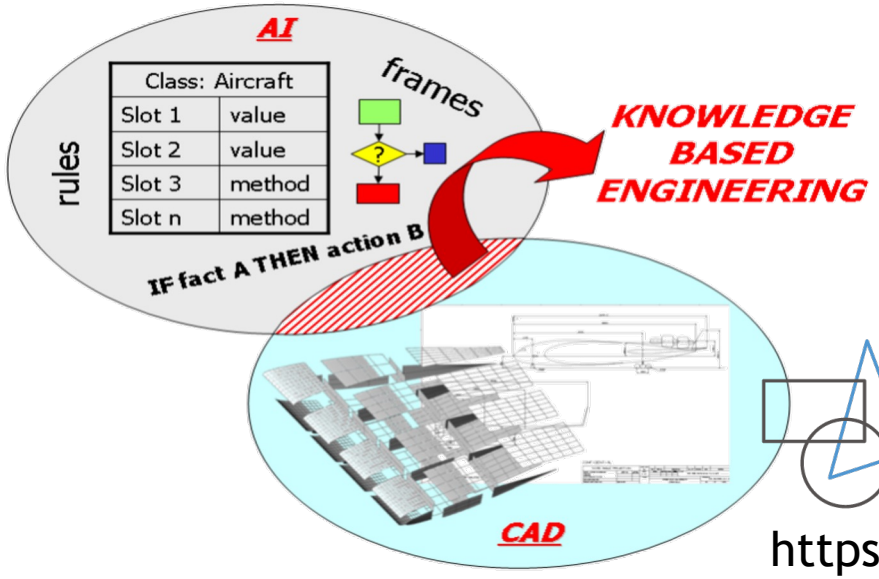
- 20% creative work
- ~~80% repetitive tasks~~



### Manufacturing

**Steps to design robotization**

- Capture knowledge
- Model knowledge
- Translate knowledge into a symbolic codification
- Computer (re-)use codified knowledge

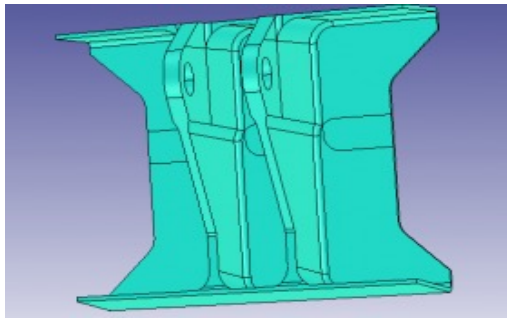


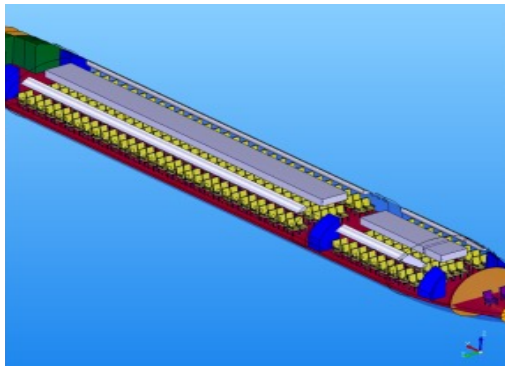

ParaPy

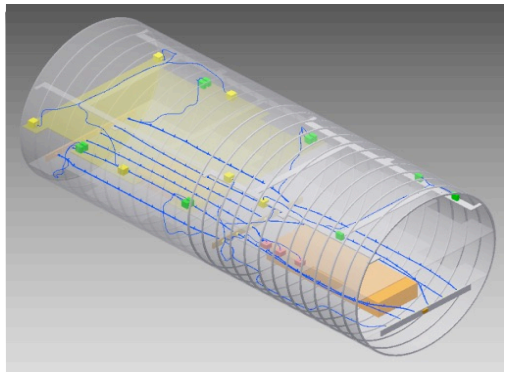
https://parapy.nl/

La Rocca, G. *Knowledge based engineering: Between AI and CAD. Review of a language based technology to support engineering design*. Advanced Engineering Informatics, 2012

# Toward a front loaded design process
## The KBE pillar

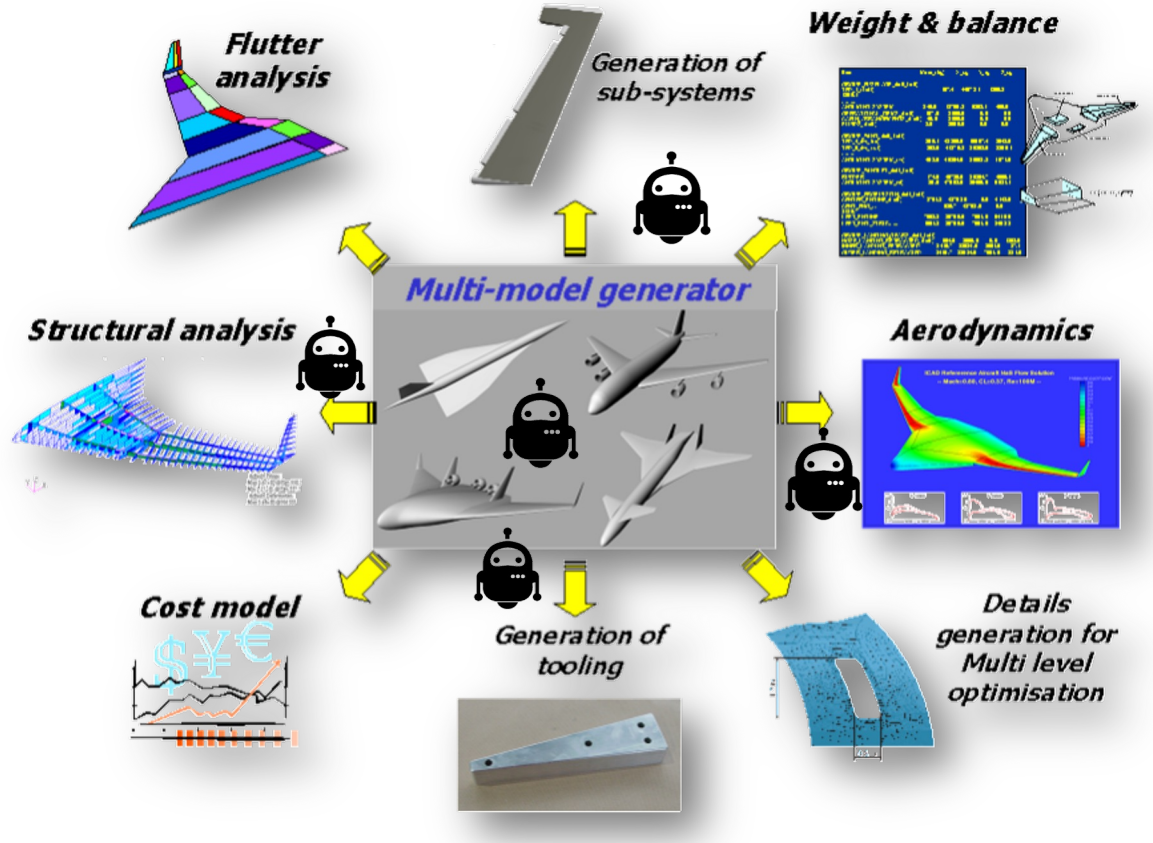






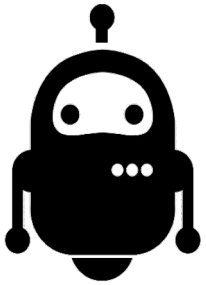
**KBE Multi-model generators:**

Combination of design automation solutions to enable the generation of product configurations & related multidisciplinary abstractions



# Toward a front loaded design process
## The KBE pillar

design robot



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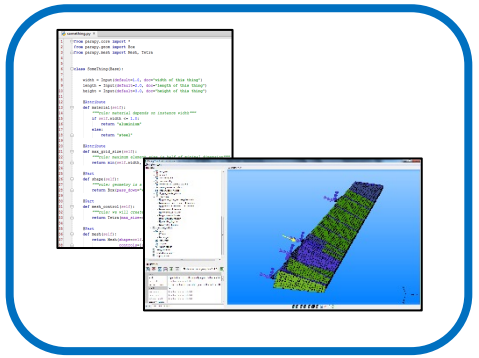
KBE app



- The steps* to build a KBE app are not trivial. Expertise and time required.
- Intensive coding effort
- A convenient methodological approach to develop KBE apps is missing

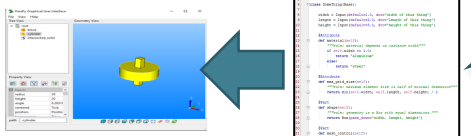
***Steps to design robotization**

- Capture knowledge
- Model knowledge
- Translate knowledge into a symbolic codification
- Computer (re-)use codified knowledge

# Toward a front loaded design process

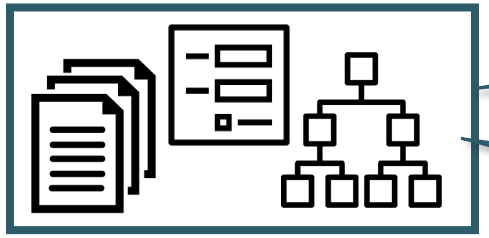
## MBSE approach to support KBE

Code parsers to strip coded knowledge

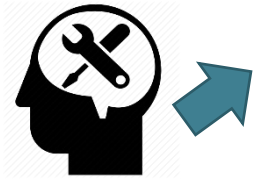


Existing KBE app

Model-based knowledge repository and editor



The MBSE *single source of truth*

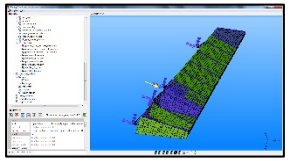


Discipline Expert

Knowledge models based on SysML

Knowledge models → KBE language translators

Automatically generated skeleton of the KBE app code



New KBE app

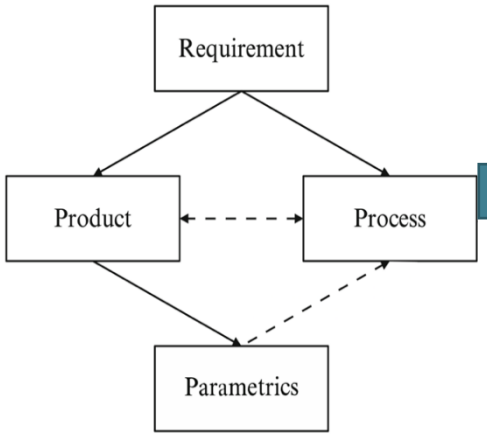
Manual completion of source code

KBE developer

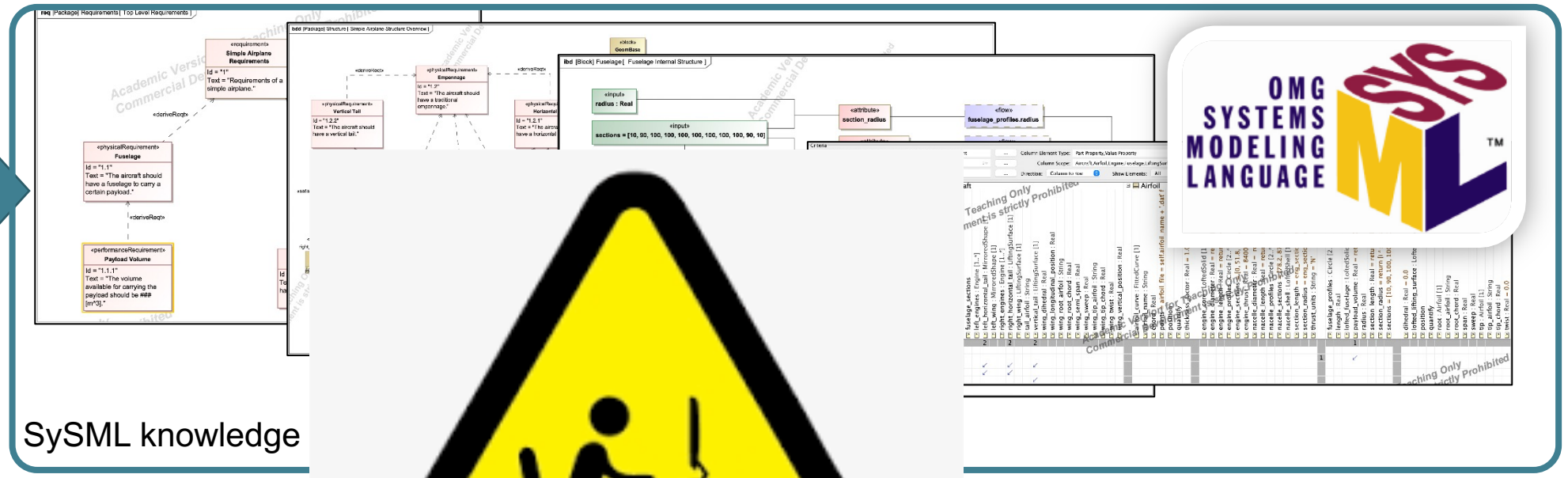
Source code is one view of the knowledge model

# Toward a front loaded design process

## MBSE approach to support KBE



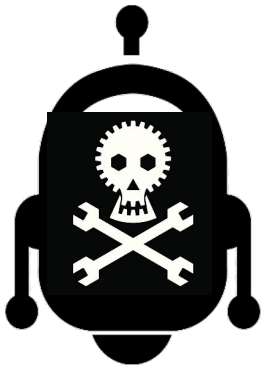

Main ontology concepts




SySML knowledge

***Export File***


*n*

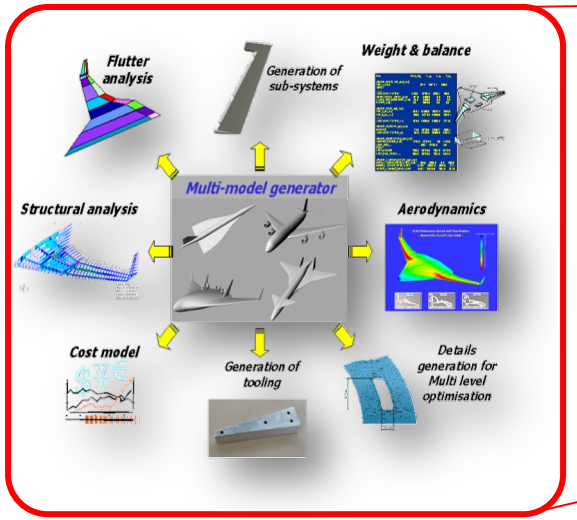



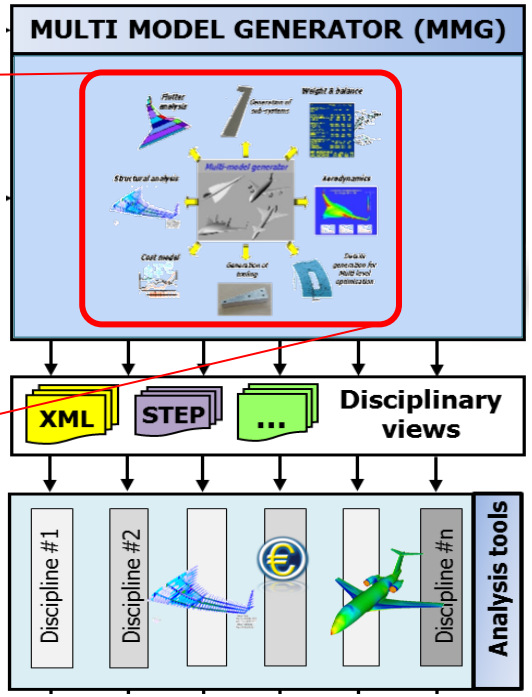
MBSE model repository

Skeleton KBE Application

# Toward a front loaded design process
## The KBE & MDAO pillars

### Multi-model generator



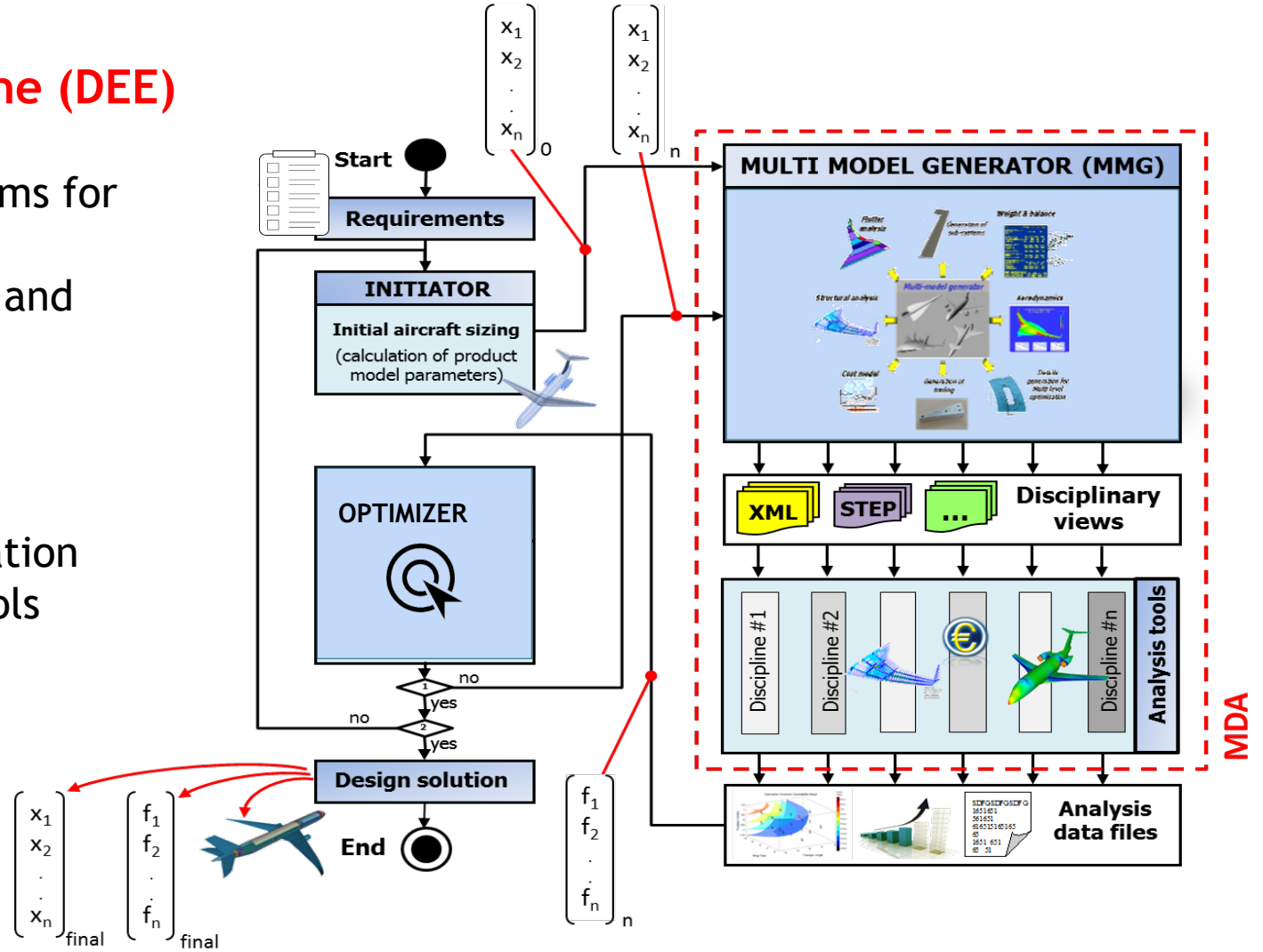

Sobieszczanski-Sobieski, A. Morris, M. van Tooren
"*Multidisciplinary Design Optimization Supported by Knowledge Based Engineering*", Wiley, 2015

# Toward a front loaded design process
## The KBE & MDAO pillars

### The Design Engineering Engine (DEE)

**Blueprint** of computational systems for distributed and collaborative multidisciplinary design, analysis and optimization (MDAO)

KBE model generator enables:
- geometry-in-the-loop optimization
- use of high fidelity analysis tools
- product topology changes




Sobieszczanski-Sobieski, A. Morris, M. van Tooren
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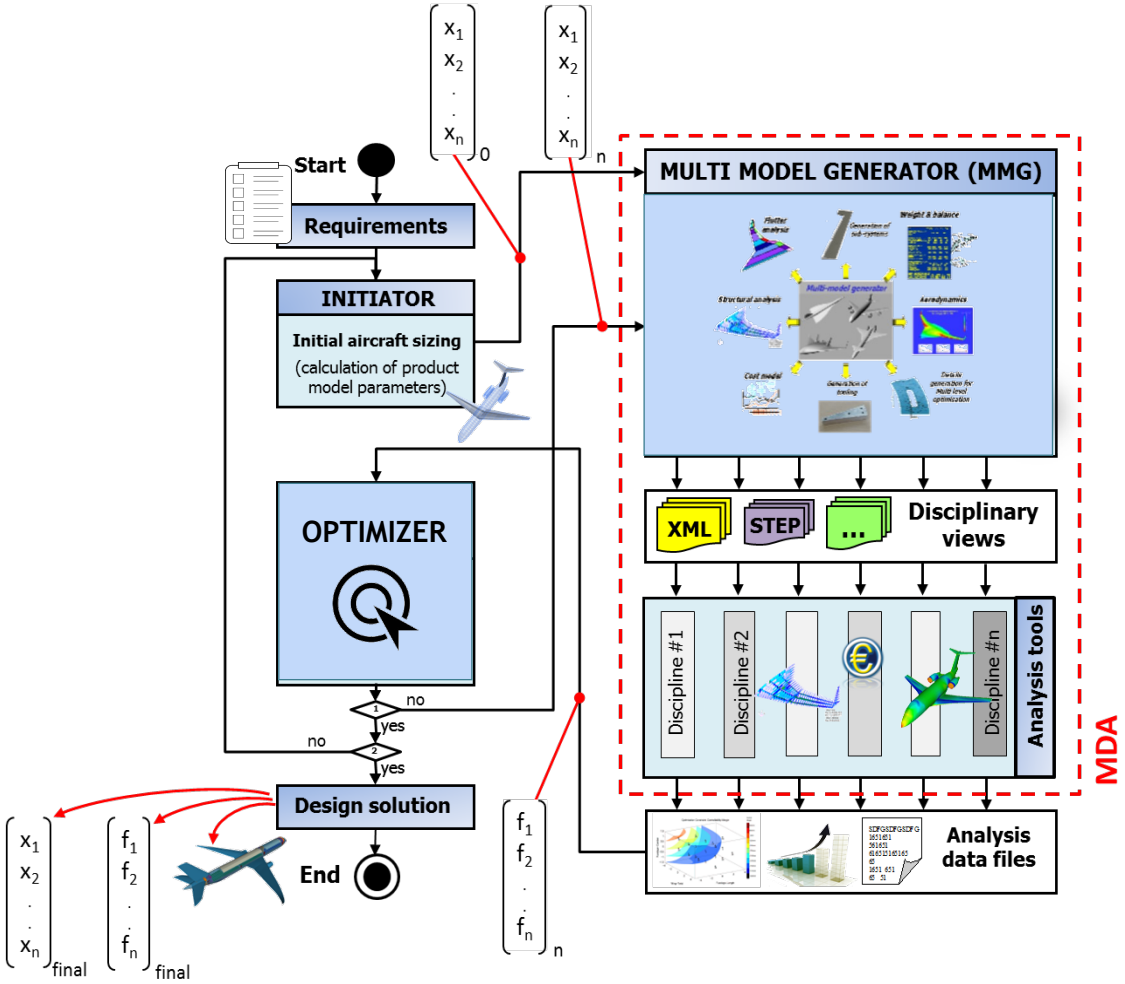
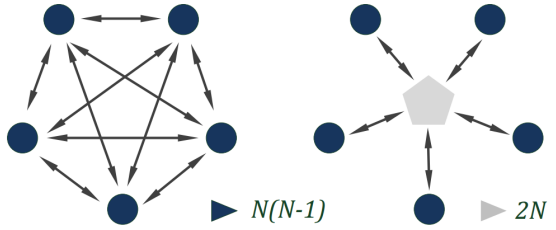
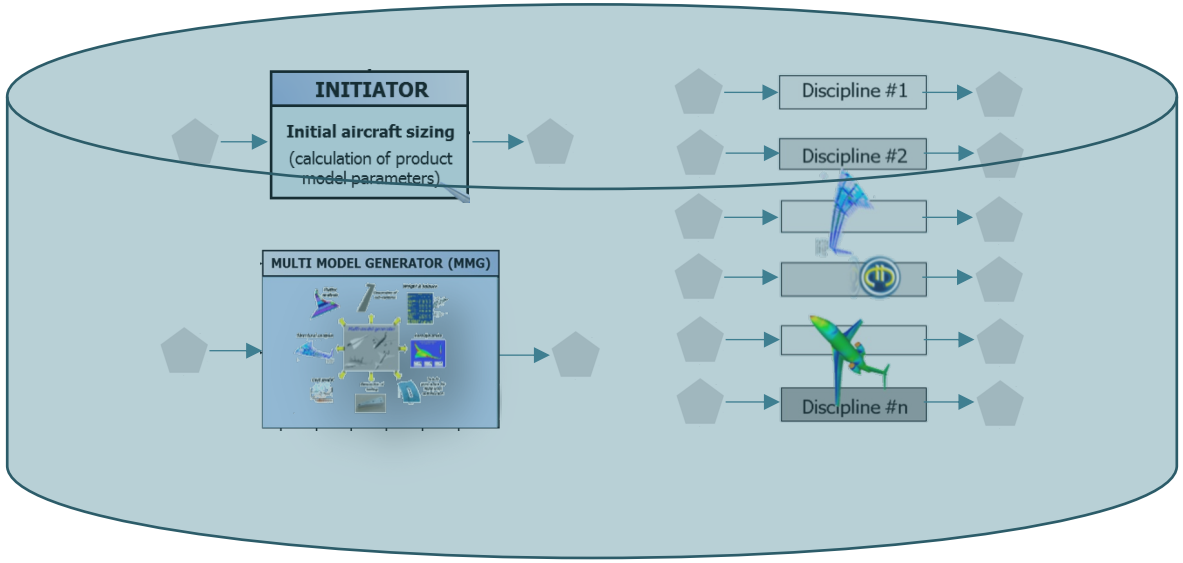
# Toward a front loaded design process
## Integration of MDAO systems




Central Data Schema

Source: Alder et al. 2020

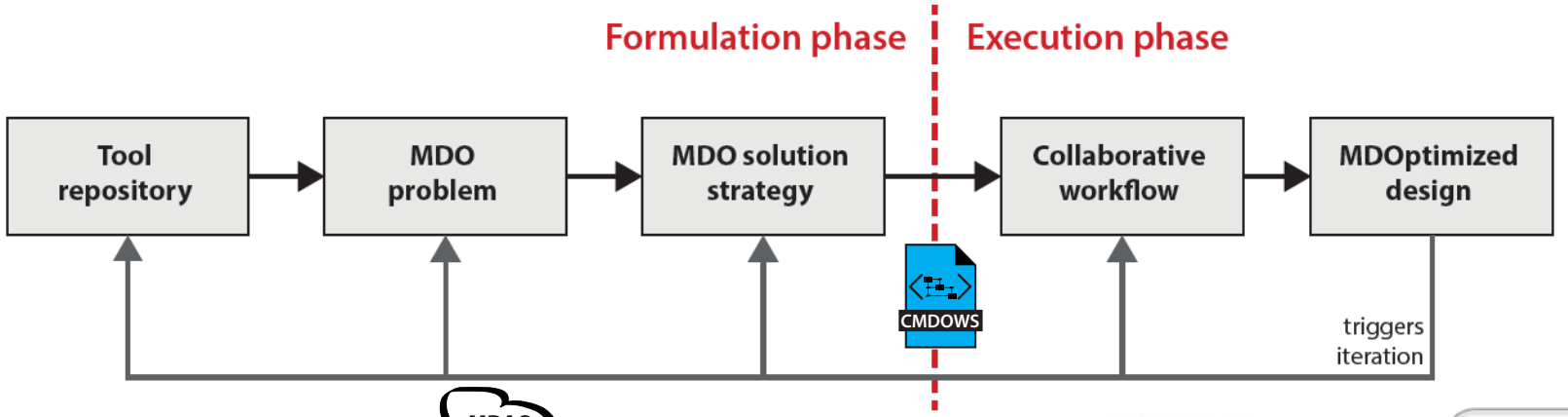


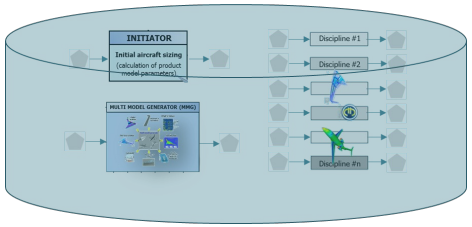

**Tool repository**

# Toward a front loaded design process
# Formulation & integration of MDAO systems

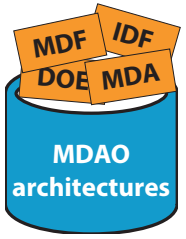
## KADMOS

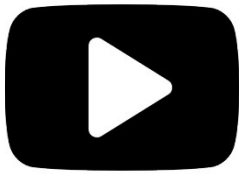
A graph manipulation system for MDAO system formulation

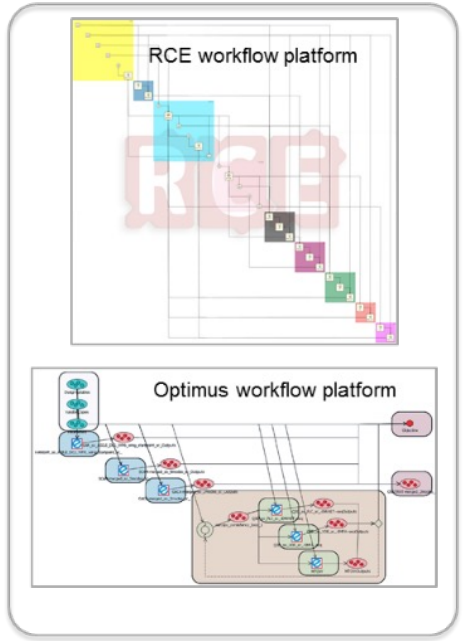




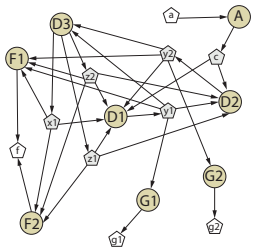


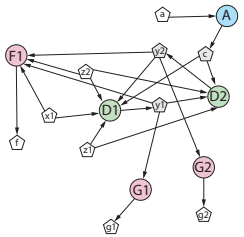



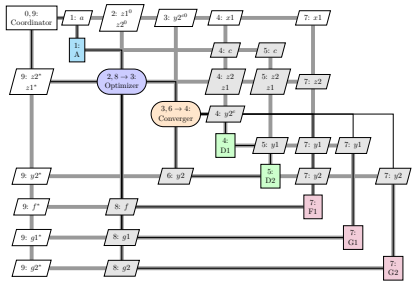



## CMDOWS

XML-based standard to store and exchange MDAO system formulations



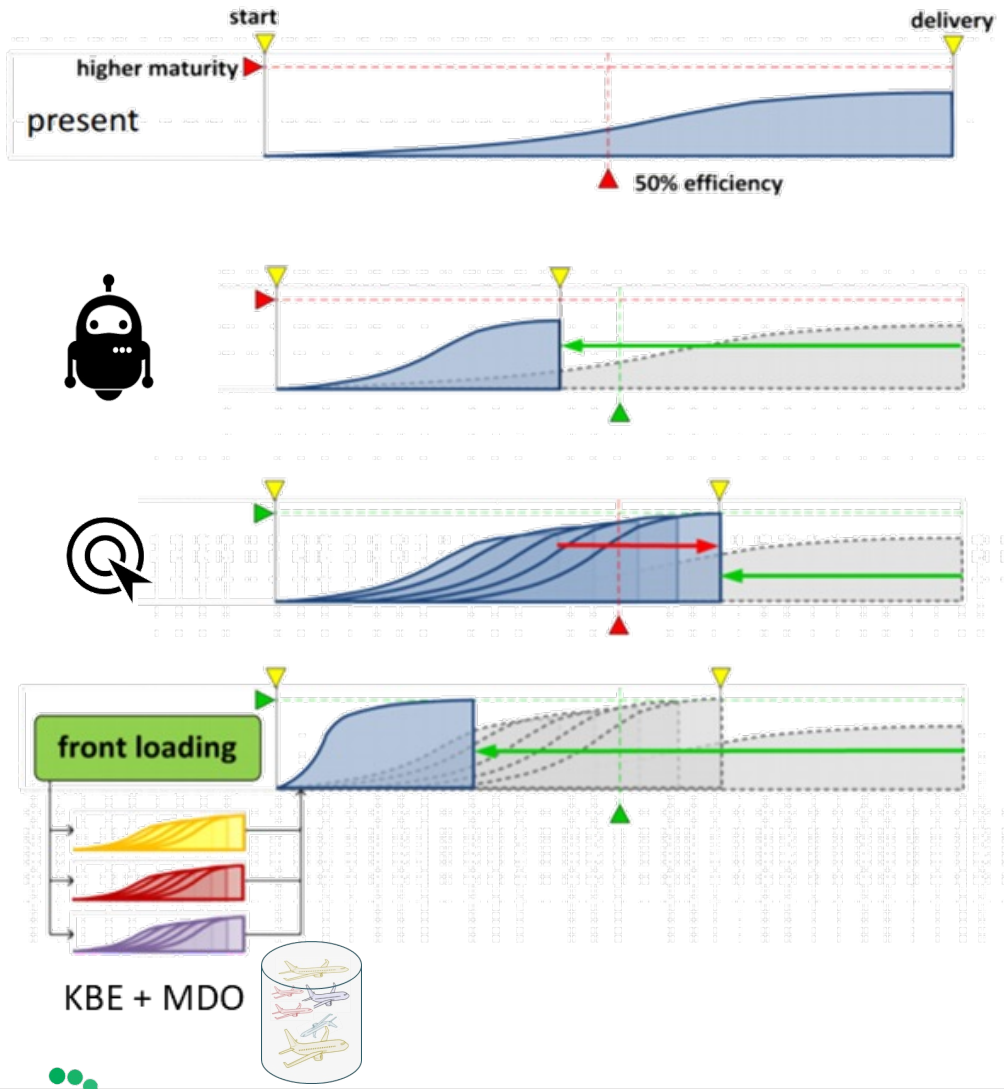





Van Gent, I., and La Rocca, G., "*Formulation and integration of MDAO systems for collaborative design: A graph-based methodological approach,*" Aerospace Science and Technology, 2019

Van Gent, I., La Rocca, G., and Hoogreef, M.F.M., "*CMDOWS: a proposed new standard to store and exchange MDO systems,*" CEAS Aeronautical Journal, 2018

# The front loaded design process




+ KBE → Shorter delivery time due to automation
→ No product performance improvement

+ MDO → Reduced time gain
→ Product performance improvement

+ KBE
+ MDO
+ pre-generated design database

= Front Loaded Design process

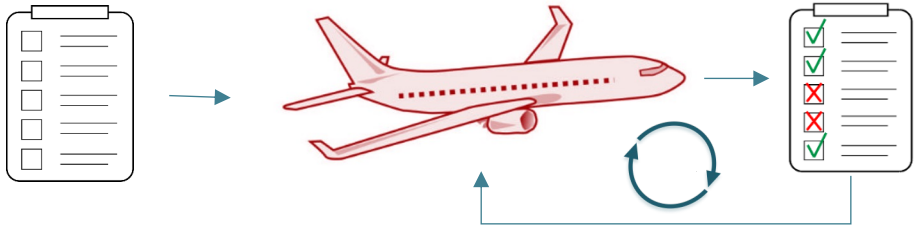
→ Short delivery time
→ Product performance improvement

# Requirement compliance

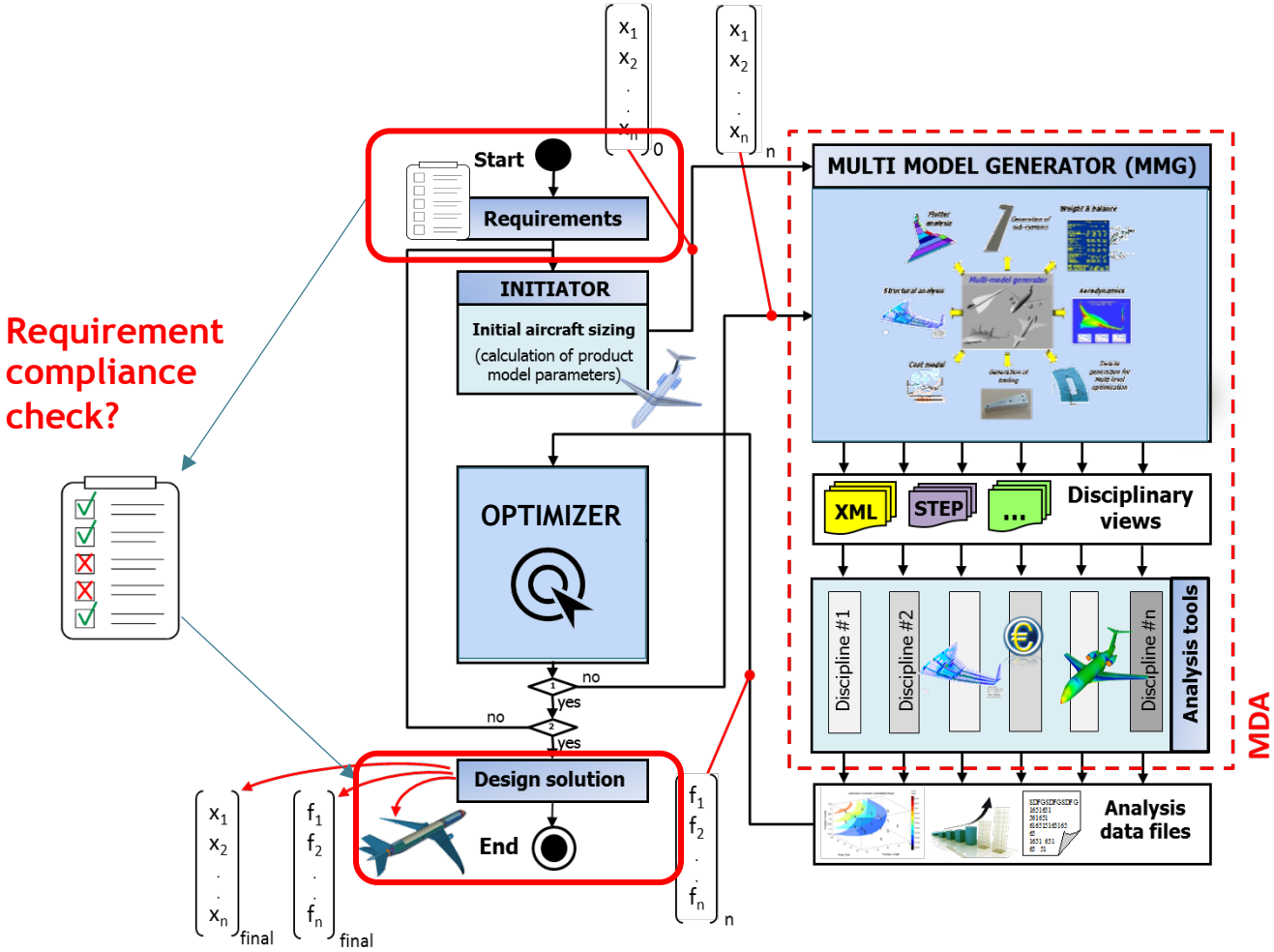
IBM Rational DOORS Next Generation

3DEXPERIENCE

jama connect™

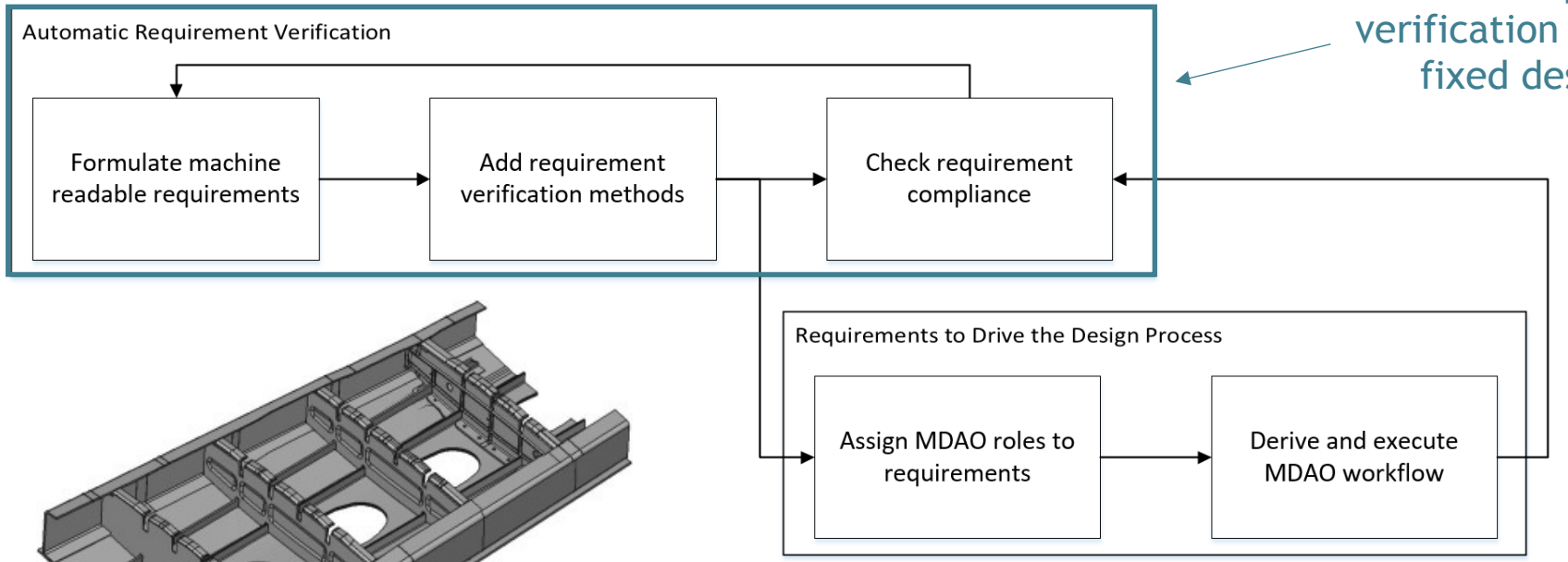



**Can I use the requirements as drivers for the MDAO process to achieve compliance?**




DEFAINE AGILE 4.0

# MBSE & MDAO for requirement compliance





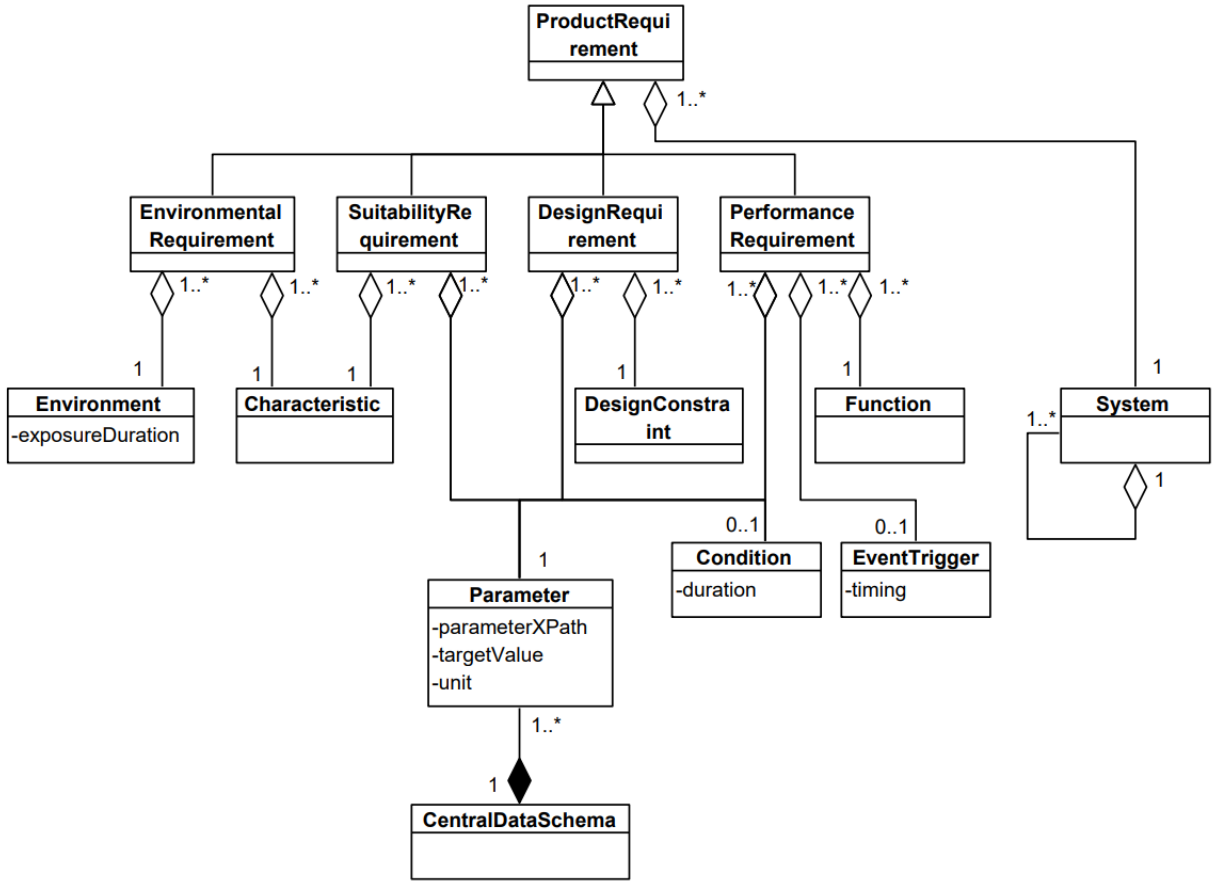

A.M.R.M. Bruggeman, G. La Rocca, B. van Manen, T. van der Laan, T. van den Berg, *'An MBSE-Based Requirement Verification Framework to Support the MDAO Process'*, AIAA Aviation Forum, 2022

# MBSE & MDAO for requirement compliance

## Requirement patterns enable the formulation of machine-readable requirements

- **Performance**
  The SYSTEM shall FUNCTION with PERFORMANCE [and TIMING upon EVENT TRIGGER] while in CONDITION
- **Design (constraint)**
  The SYSTEM shall [exhibit] DESIGN CONSTRAINTS [in accordance with PERFORMANCE while in CONDITION]
- **Environmental**
  The SYSTEM shall [exhibit] CHARACTERISTIC during/after exposure to ENVIRONMENT [for EXPOSURE DURATION]
- **Suitability**
  The SYSTEM shall exhibit CHARACTERISTIC with PERFORMANCE while CONDITION [for CONDITION DURATION]

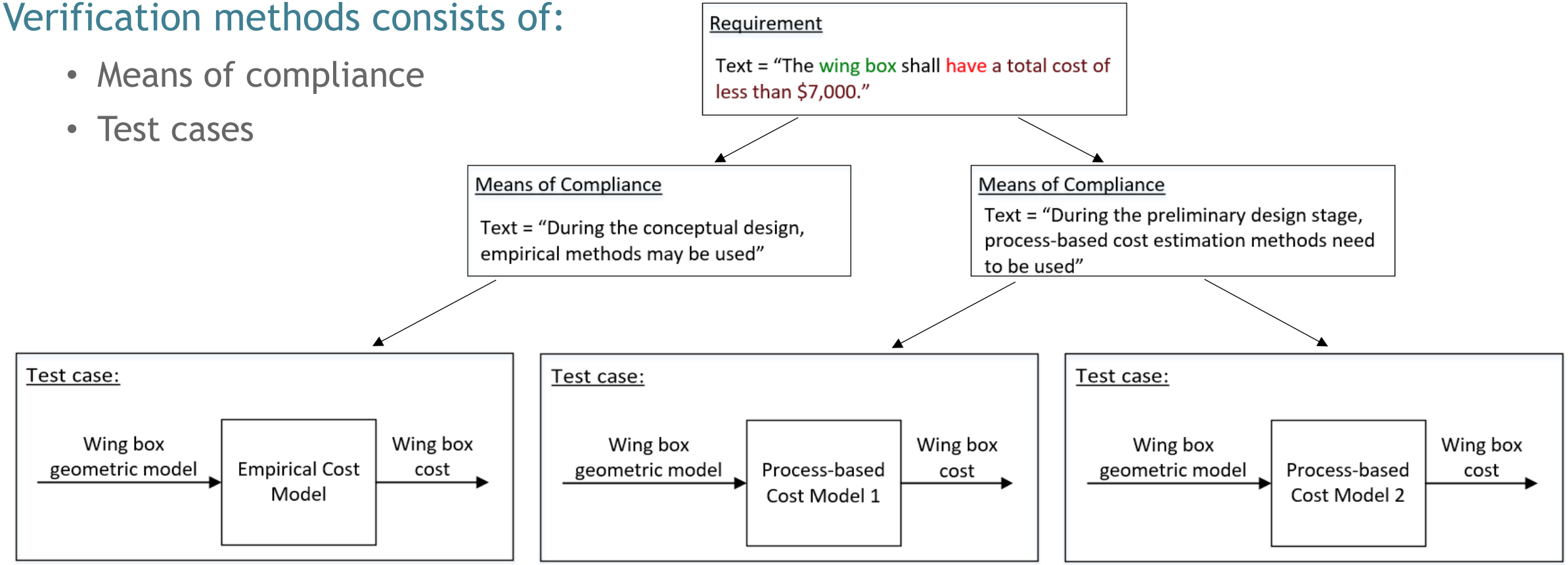
Source: Boggero et al (2020), patterns from Carson (2015)



# MBSE & MDAO for requirement compliance

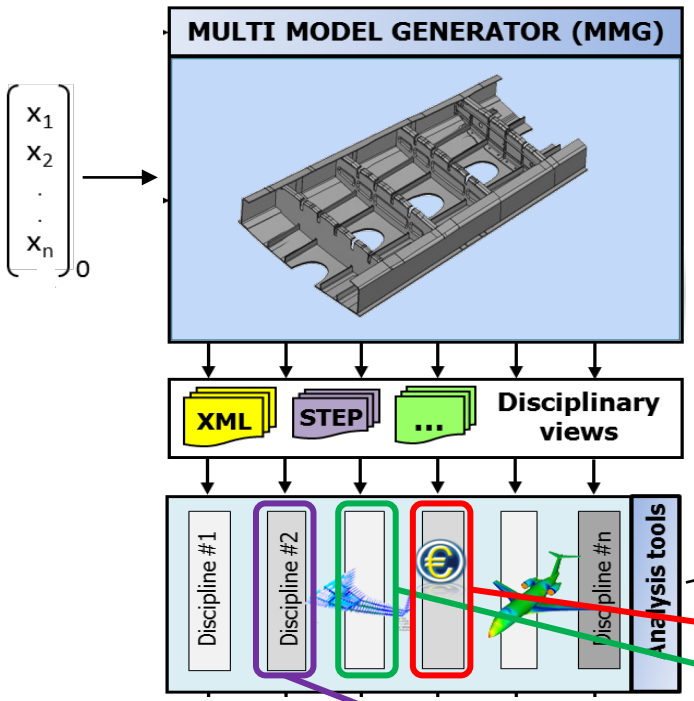
## Verification methods consists of:

- Means of compliance
- Test cases

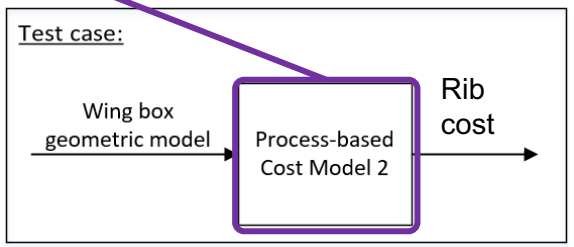


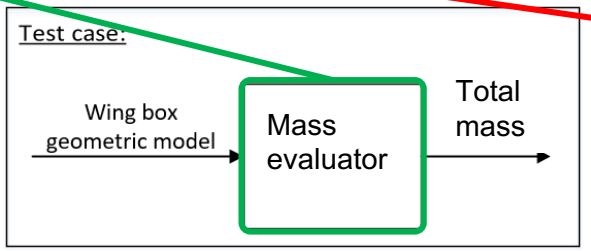
# MBSE & MDAO for requirement compliance

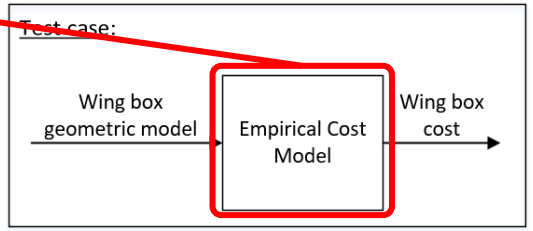
## Automatic generation of requirement compliance report




| | Requirements | Textual Requirements | Compliance | Value | Unit | Difference |
|---|---|---|---|---|---|---|
| R-1001 | total cost | The wingbox shall have a total cost of less than $7000 | True | 824.35 | $ | 2.51% |
| R-1002 | total rib cost | The wingbox shall have a total rib cost of less than $1600 | False | 710.09 | $ | -6.88% |
| R-1003 | total mass | The wingbox shall have a total mass of less than 50 k | False | 7.97 | kg | -15.93% |
| R-2001 | root chord | The wingbox shall have a root chord of in the range of [3000, 3500] mm | False | 537.21 | mm | 7.43/6.00% |
| R-2002 | span | The wingbox shall have a span of in the range of [3500, 4000] mm | True | 757.34 | mm | 18.00/-1.14% |

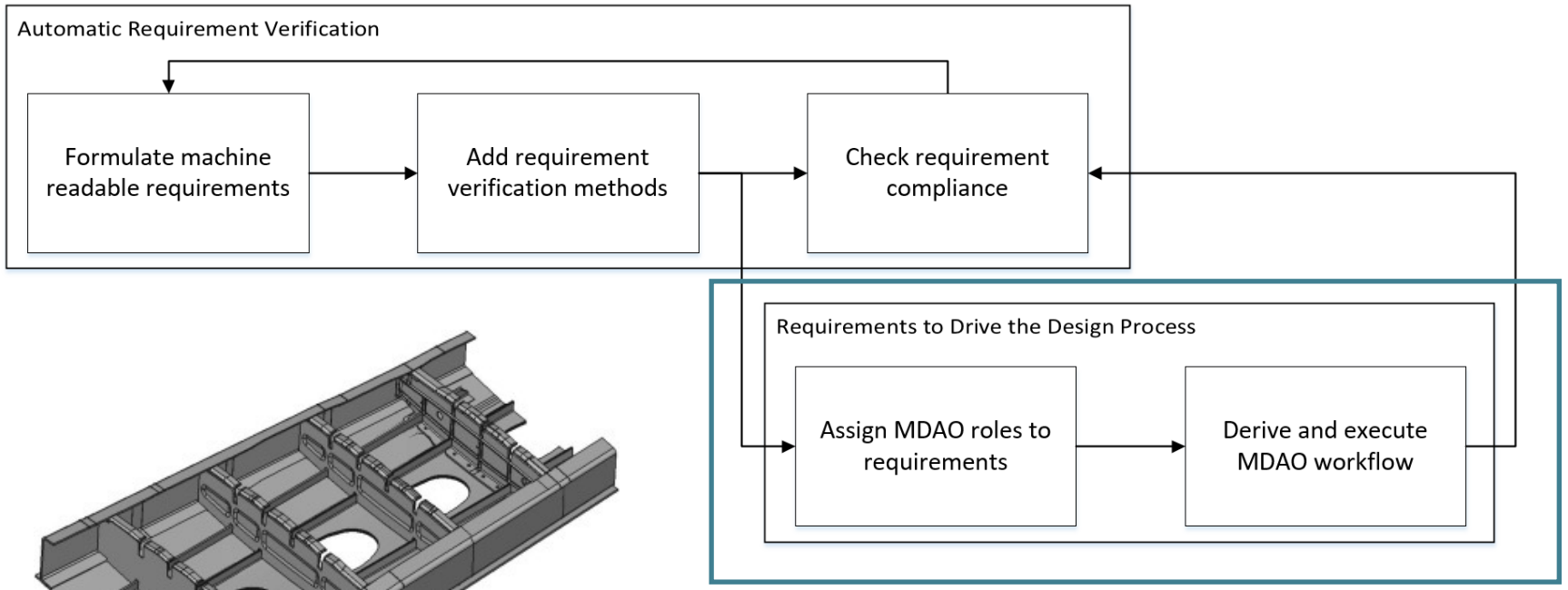


# MBSE & MDAO for requirement compliance

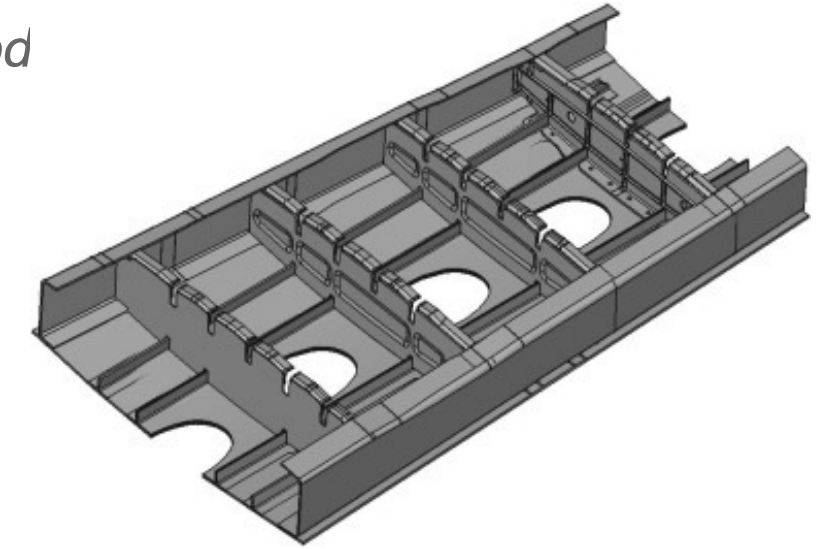
## Requirements to drive the design process



# MBSE & MDAO for requirement compliance

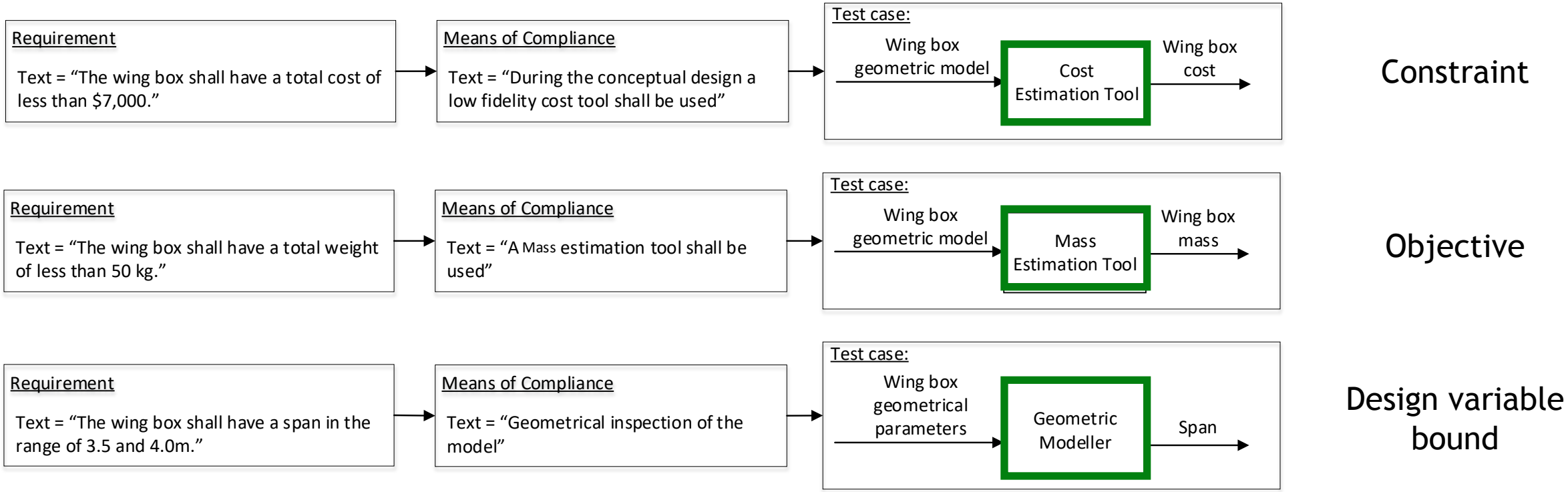
## User assigns MDAO roles to the requirements

- *Constraint……Cost < $7000*
- *Objective……Mass < 50 kg*
- *Design variable……In-house production method*
- *Design variable bound... Span < 4.0 m*
- *Input parameter……n = 2.5*
- *Quantity of Interest……*



# MBSE & MDAO for requirement compliance

## Design competences from test cases and problem roles determine MDAO system



# MBSE & MDAO for requirement compliance

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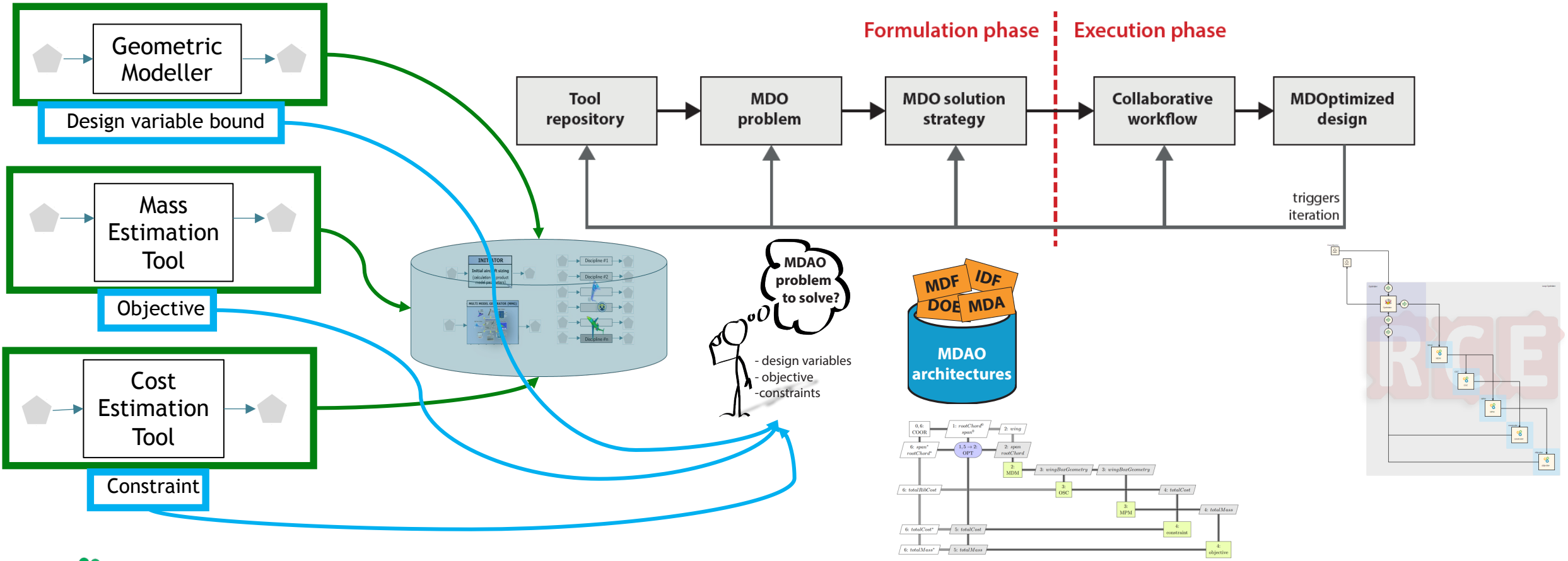
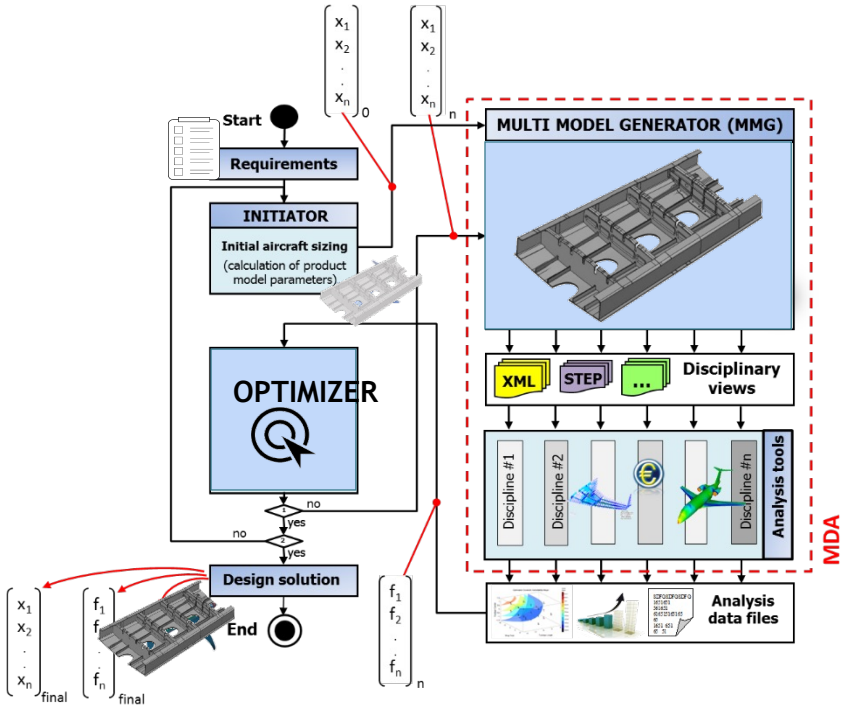
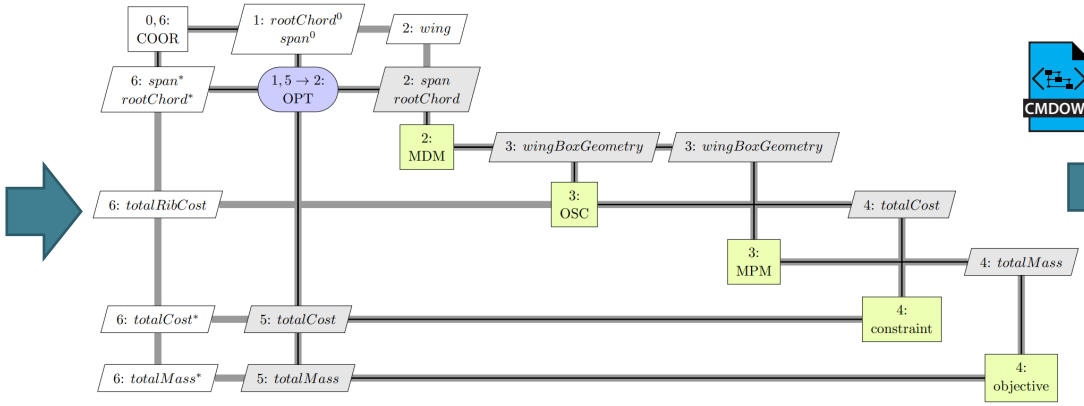


# MBSE & MDAO for requirement compliance

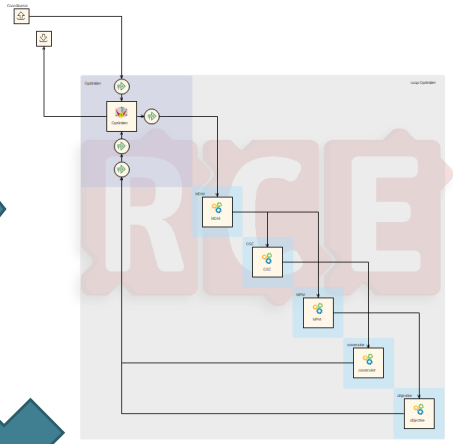
## Design competences from test cases and problem roles determine the MDAO workflow





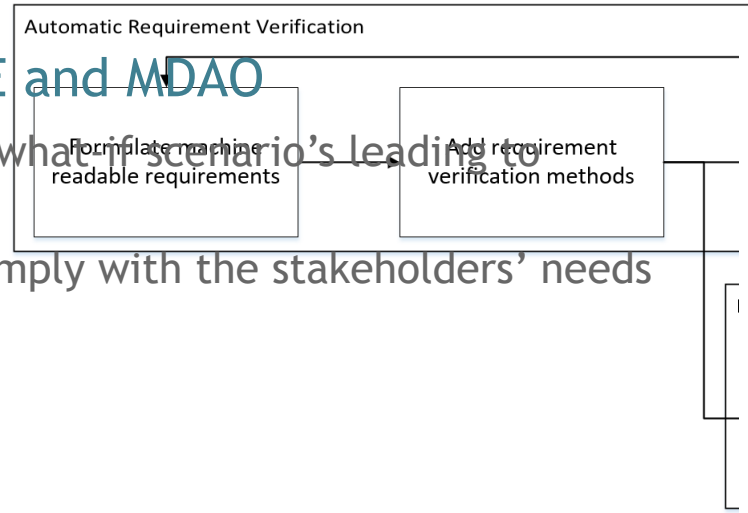


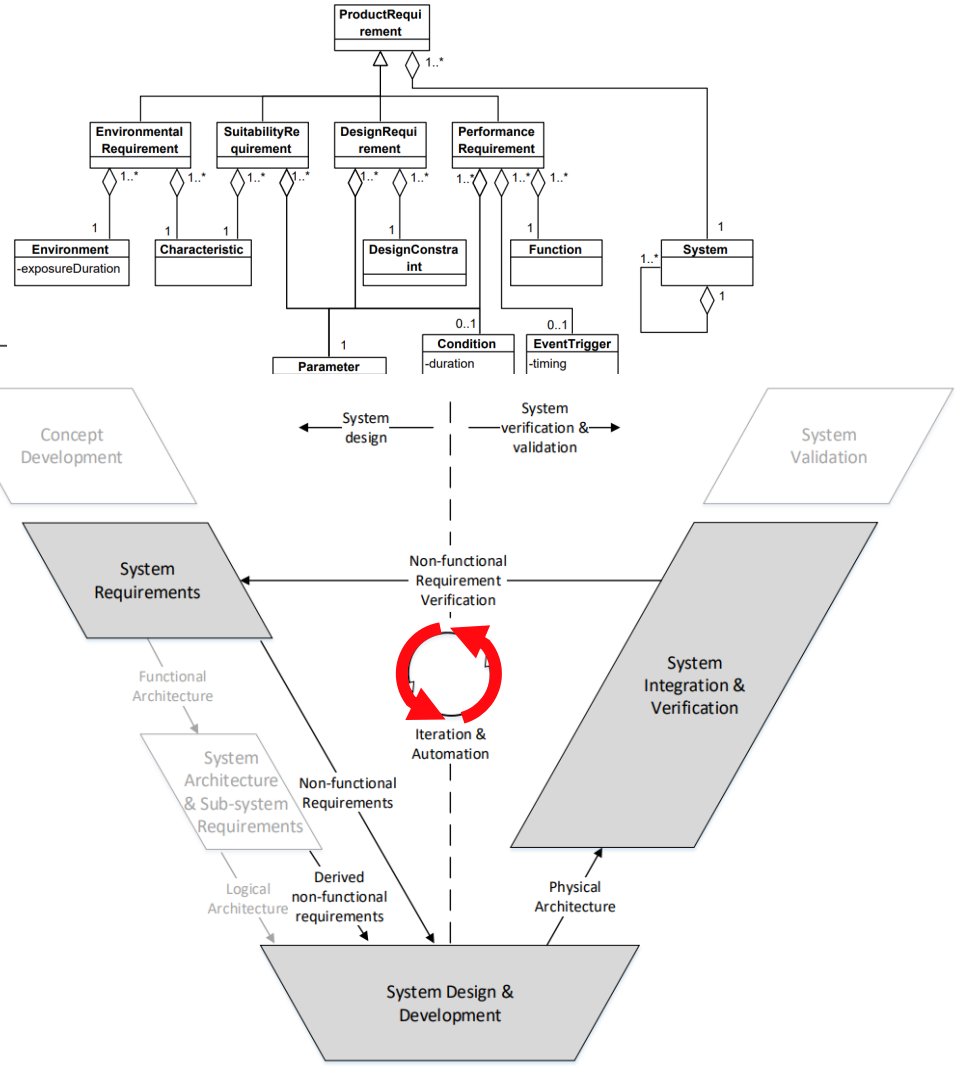


| | Requirements | Textual Requirements | Compliance | Value | Unit | Difference |
|---|---|---|---|---|---|---|
| R-1001 | total cost | The wingbox shall have a total cost of less than $7000 | True | 6017.00 | $ | 14.04% |
| R-1002 | total rib cost | The wingbox shall have a total rib cost of less than $1600 | True | 1538.00 | $ | 3.88% |
| R-1003 | total mass | The wingbox shall have a total mass of less than 50 k | True | 42.28 | kg | 3.44% |
| R-2001 | root chord | The wingbox shall have a root chord of in the range of [3000, 3500] mm | True | 3000.00 | mm | 0.00/14.29% |
| R-2002 | span | The wingbox shall have a span of in the range of [3500, 4000] mm | True | 3500.00 | mm | 0.00/12.50% |

# To summarize

- Requirements Verification Framework
  - Enables automatic verification of requirements
  - Let requirements drive the design process
- Direct link between MBSE and MDAO
  - Enables the evaluation of what-if scenario's leading to better design choices
  - Optimized designs that comply with the stakeholders' needs



# Toward a front loaded design process

## MBSE-based methodologies to support KBE and MDAO

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