RESEARCH ON MULTI-DISCIPLINARY OPTIMIZATION @ Machine Design

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Department of Management and Engineering

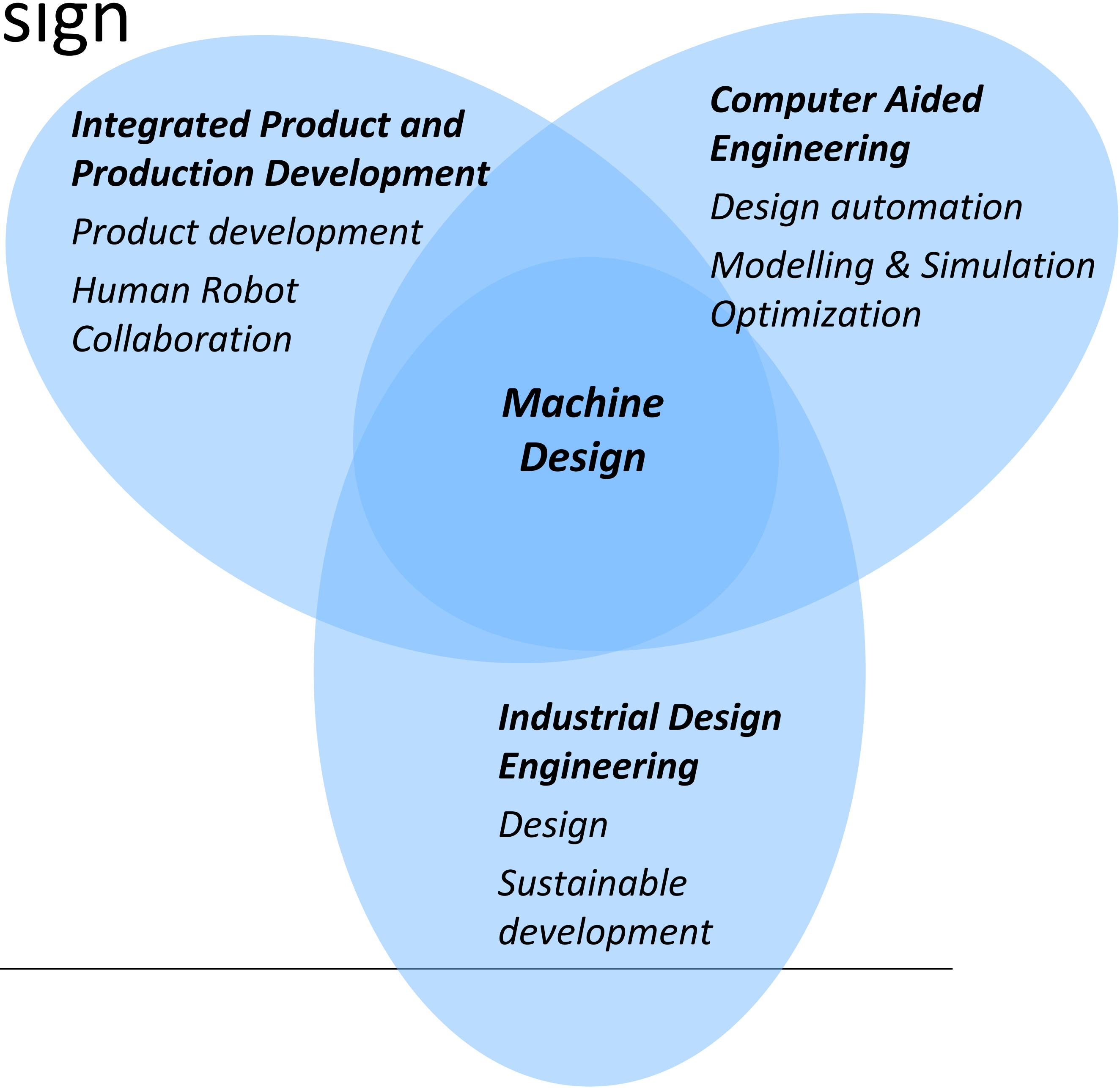
LINKÖPINGS UNIVERSITET

MODPROD Workshop 2018
6-7/2 2018, Linköping University

The Division of Machine Design

- 2 full professor
- 1 Adjoint professor
- 2 Associate professors
- 5 Senior Lecturers
- 7 Lecturers
- 3 Post docs
- 6 PhD students
- 1 Industrial PhD student
- 2 Technicians
- 1 administrator

In total 30 persons, 24 FTE + ind. PhD students
Budget: Education 26 MSEK
Research 9 MSEK



What is MDO?

"a method for the design of complex technical systems and subsystems that consistently exploit synergies between interrelated phenomena”

Giesing et al. 1998

“Multidisciplinary design optimization (MDO) is a field of research that studies the application of numerical optimization techniques to the design of engineering systems involving multiple disciplines or components”

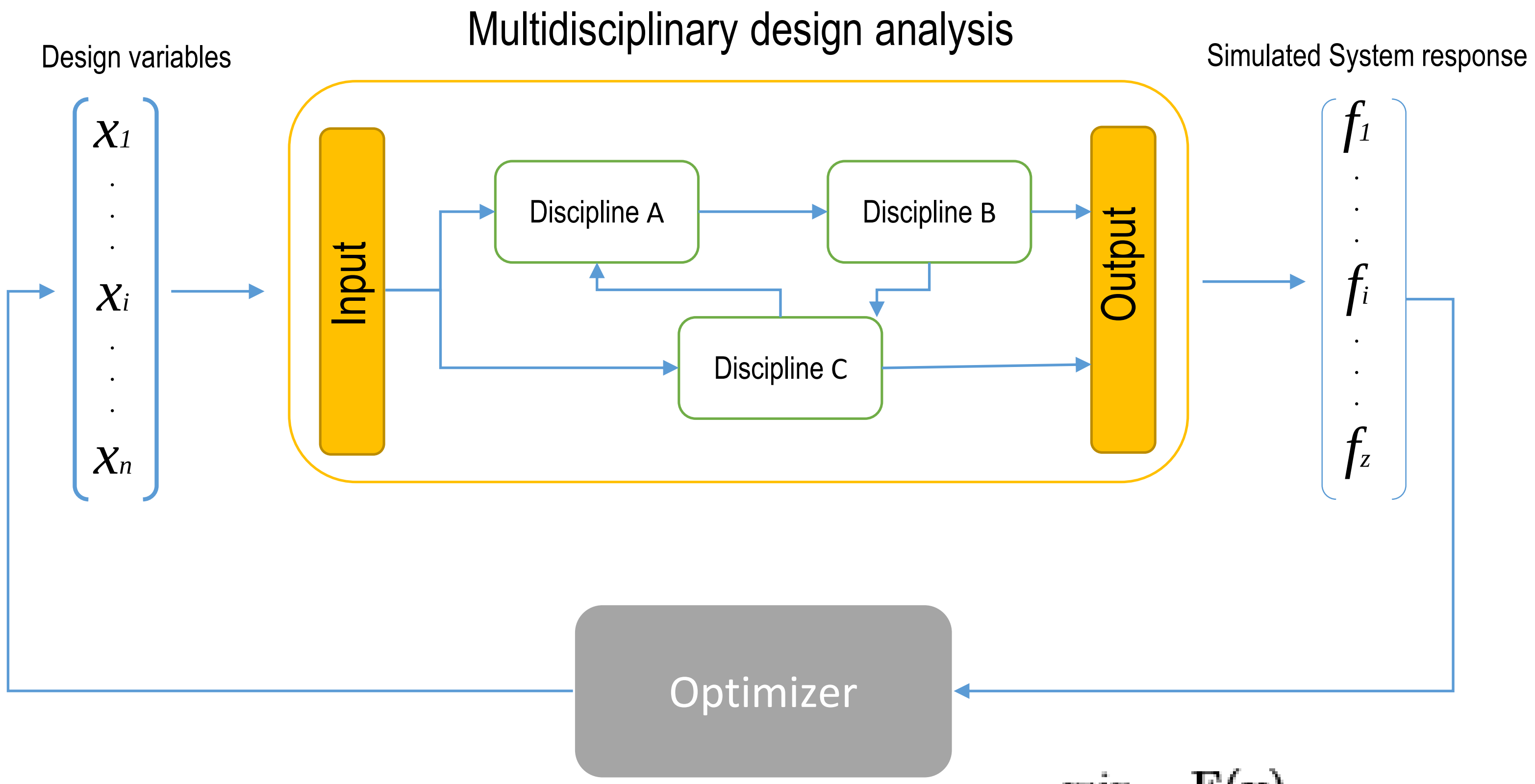
Simpson et al (2013)

“How to decide what to change, and to what extent to change it, when everything influences everything else.”

AIAA Technical Committee on MDO (1998)

MDO - visualization

MDO – problem formulation



min	$\mathbf{F}(\mathbf{x})$	Objective
s.t.	$\mathbf{g}(\mathbf{x}) \leq 0$	Inequality constraints
	$\mathbf{h}(\mathbf{x}) = 0$	Equality constraints
	$x_{i,LB} \leq x_i \leq x_{i,UB}$	Variable bounds
where	$\mathbf{F} = [f_1(\mathbf{x}) \ \ldots \ f_z(\mathbf{x})]^T$	
	$\mathbf{x} = [x_1 \ \ldots \ x_i \ \ldots \ x_n]^T$	Design vector

MDO Challenges

The use of MDO in industry is limited as it is hampered due to barriers of technical, organizational cultural and educational nature.

Agte et al. (2009)

At an NSF workshop with academics and industrialist participants the challenges of implementing MDO in industry were categorized into 5 topics:

1. Modeling and design space
2. Metrics, objectives and requirement
3. Coupling of complex engineered systems
4. Dealing with uncertainty
5. People and workflow

Simpson and Martins (2011)

Design automation

An enabler for MDO

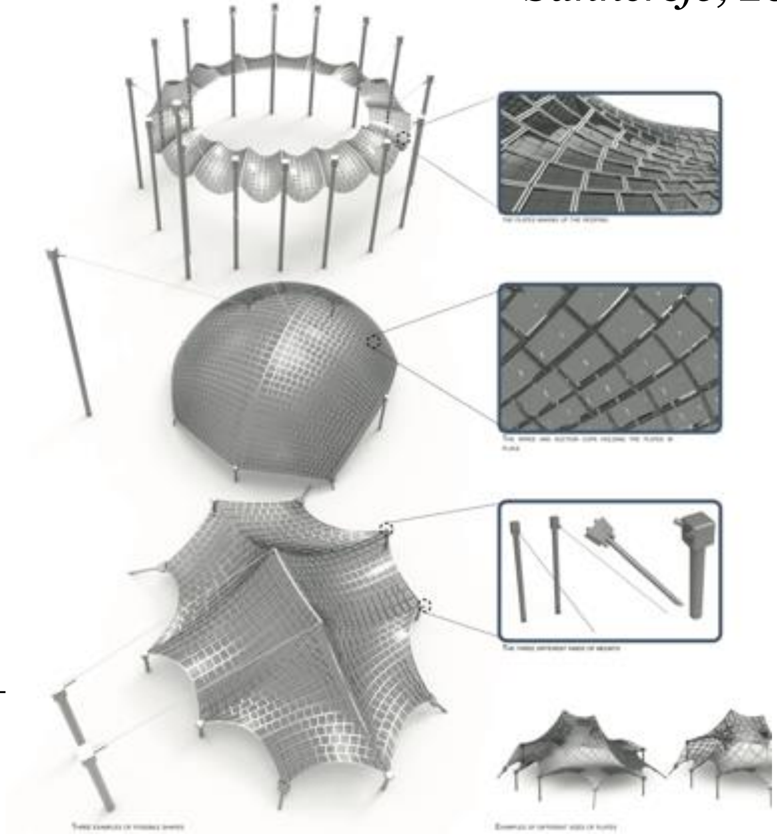
Design Automation and parametric CAD modeling

"minimize repetitive and non-creative design activities"

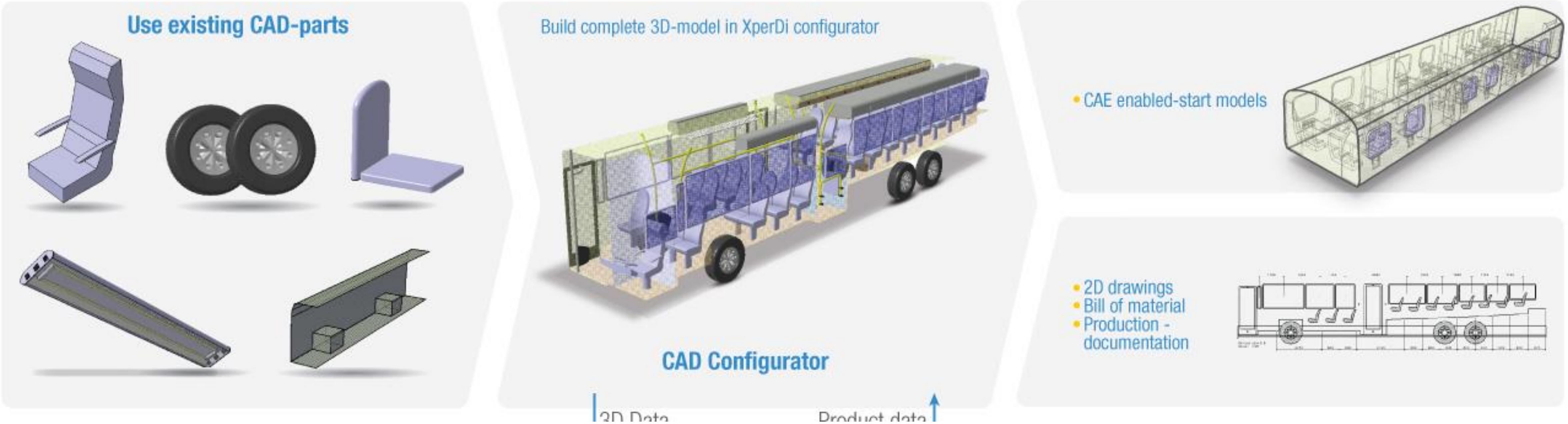
Tarkian, 2012

"to allow reuse of existing design solutions with adaptations to new specifications"

Sunnersjö, 2006



Design automation and Knowledge Based Engineering



www.xperdi.se

Different levels of Design Automation

Manual CAE

- Manual configuration
- Manual pre-processing
- Manual sim submission
- Manual postprocessing

➔ Lot of ”clicking”

Scripted CAE

- Manual configuration
- Scripted pre-processing
- Scripted sim submission
- Manual postprocessing

➔ Less ”clicking”

Automated CAE

- Scripted configuration
- Scripted pre-processing
- Scripted sim submission
- Scripted postprocessing

➔ No”clicking”, Enables batch runs

Scheduled CAE

- Scheduled simulation
- Design exploration
- Single-disciplinary design optimization

➔ ”Sub optimization”

Collaborative CAE

- Multi-disciplinary design optimization
- Multi variate analysis
- Pareto designs

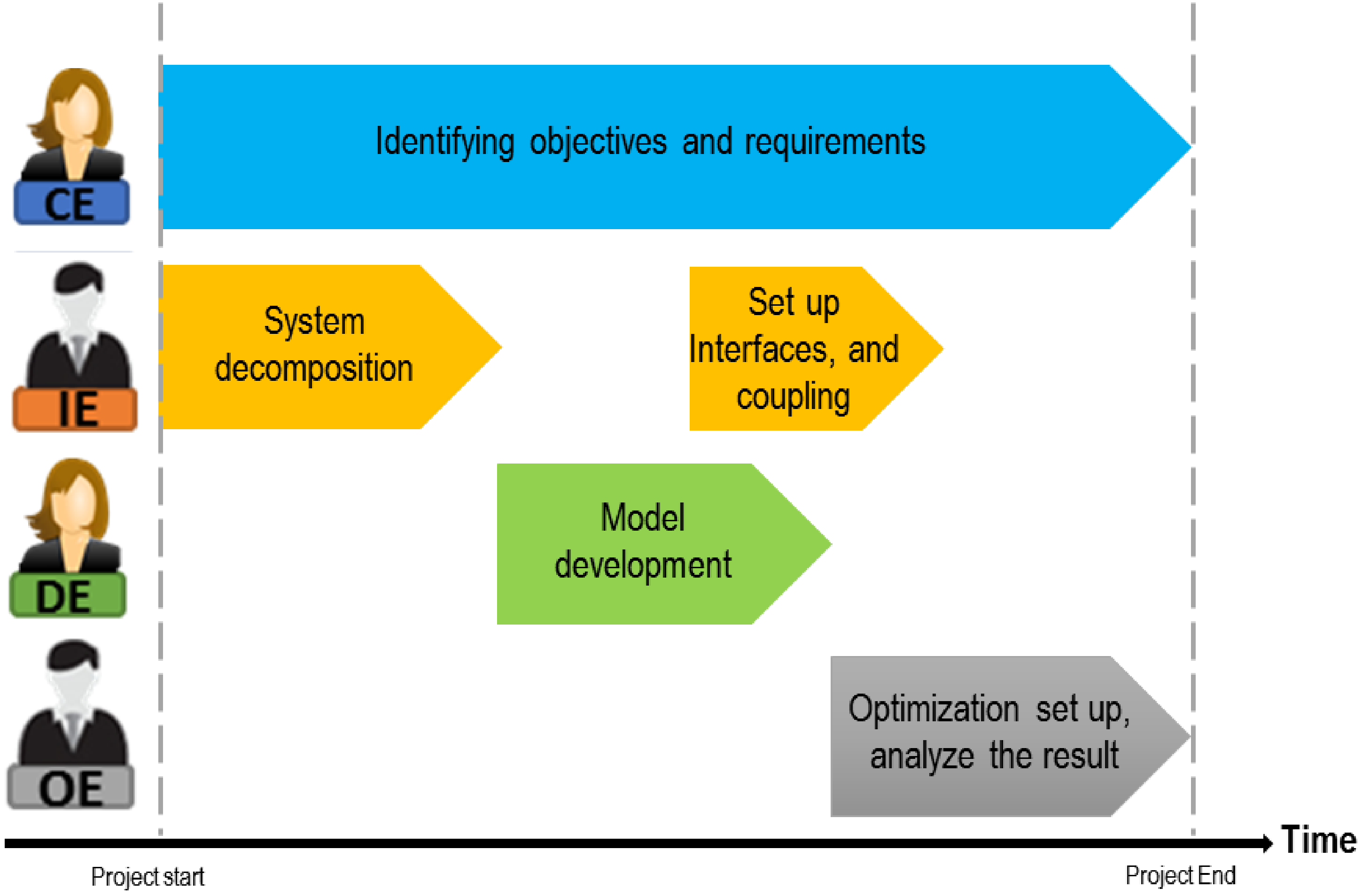
➔ Trade-off balancing

MDO in Conceptual design and Product development

Roles and processes for efficient MDO

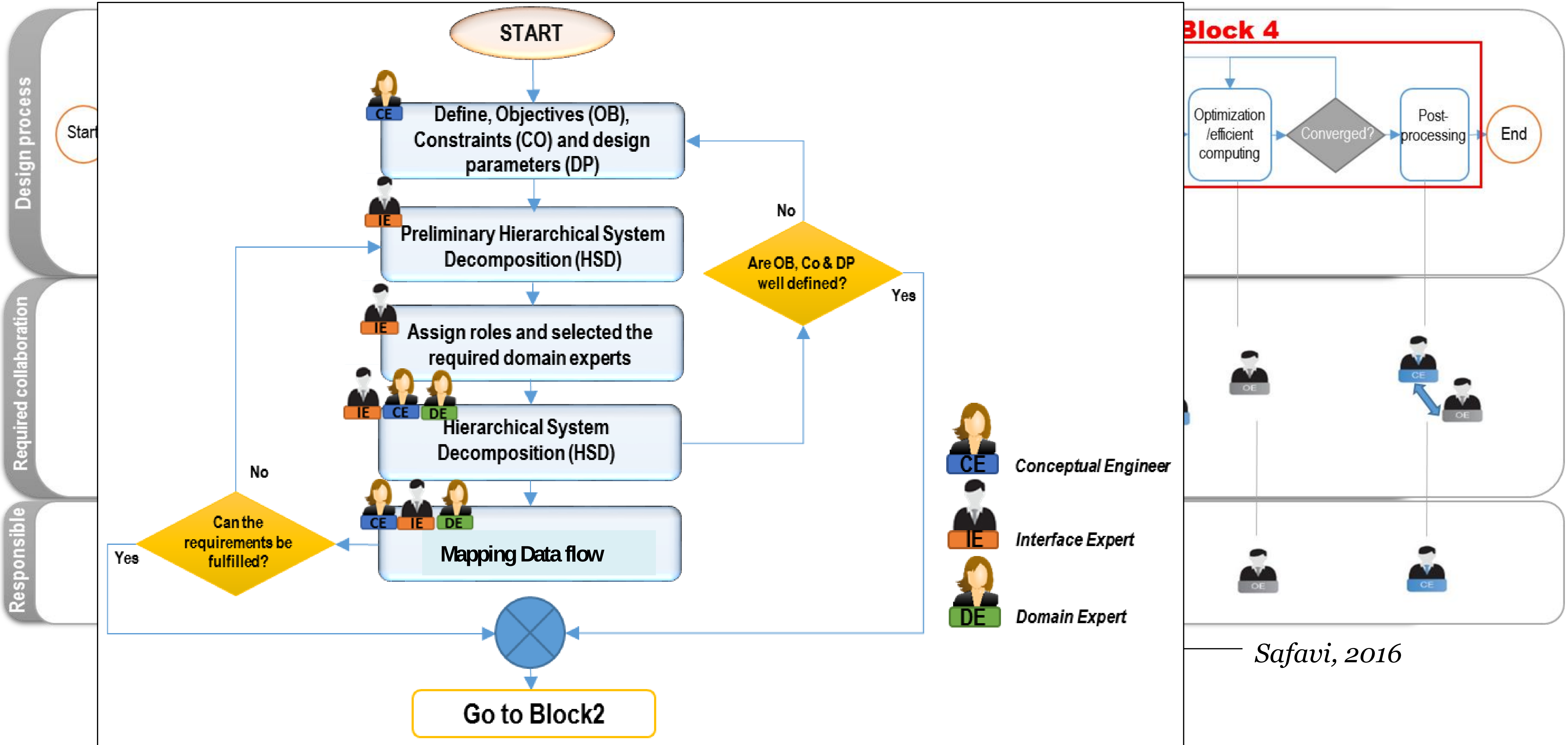
Roles for successful MDO in the PDP

- Conceptual Engineer (**CE**)
  - Identify objectives and requirements
- Interface Expert (**IE**)
  - System decomposition
  - Framework integration
- Domain Expert (**DE**)
  - Specialist within a certain field
- Optimization Expert (**OE**)
  - Formulate MDO problem
  - Run optimizations



Safavi, 2016

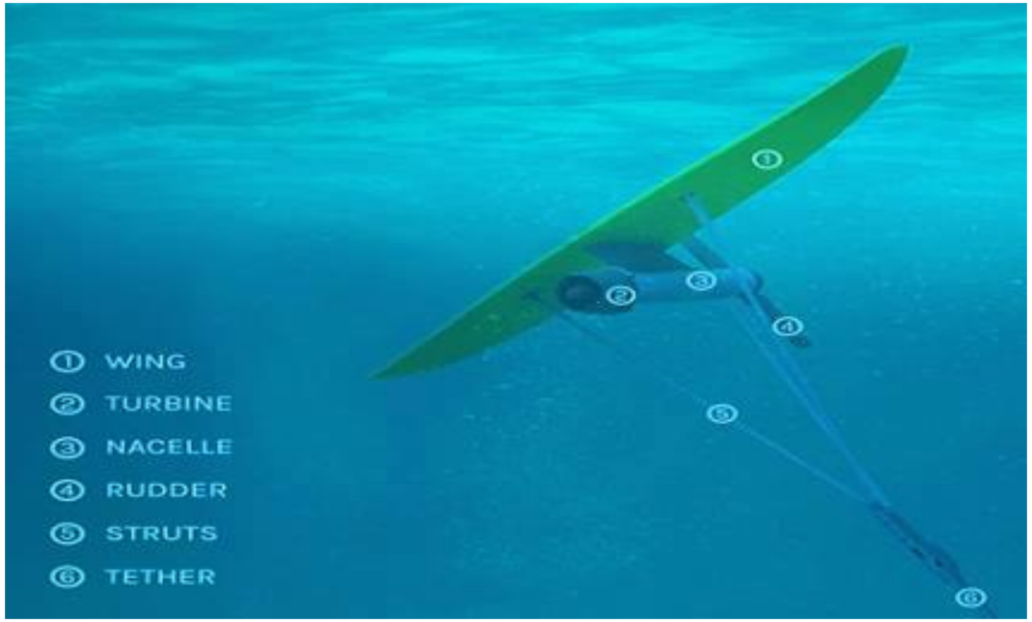
Collaborative MDO – the process

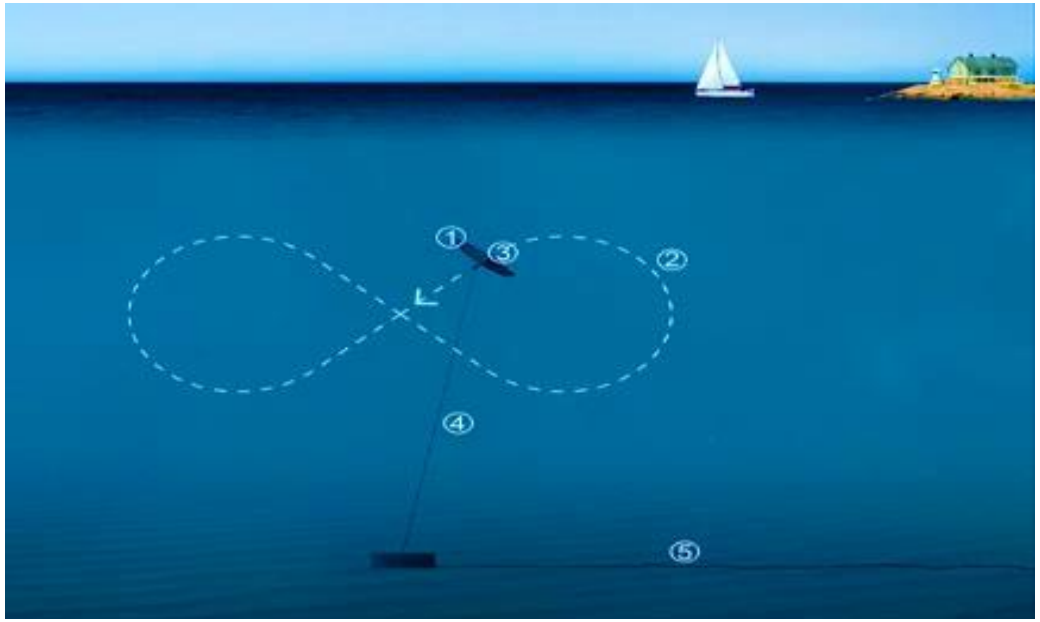


Safavi, 2016

Application examples

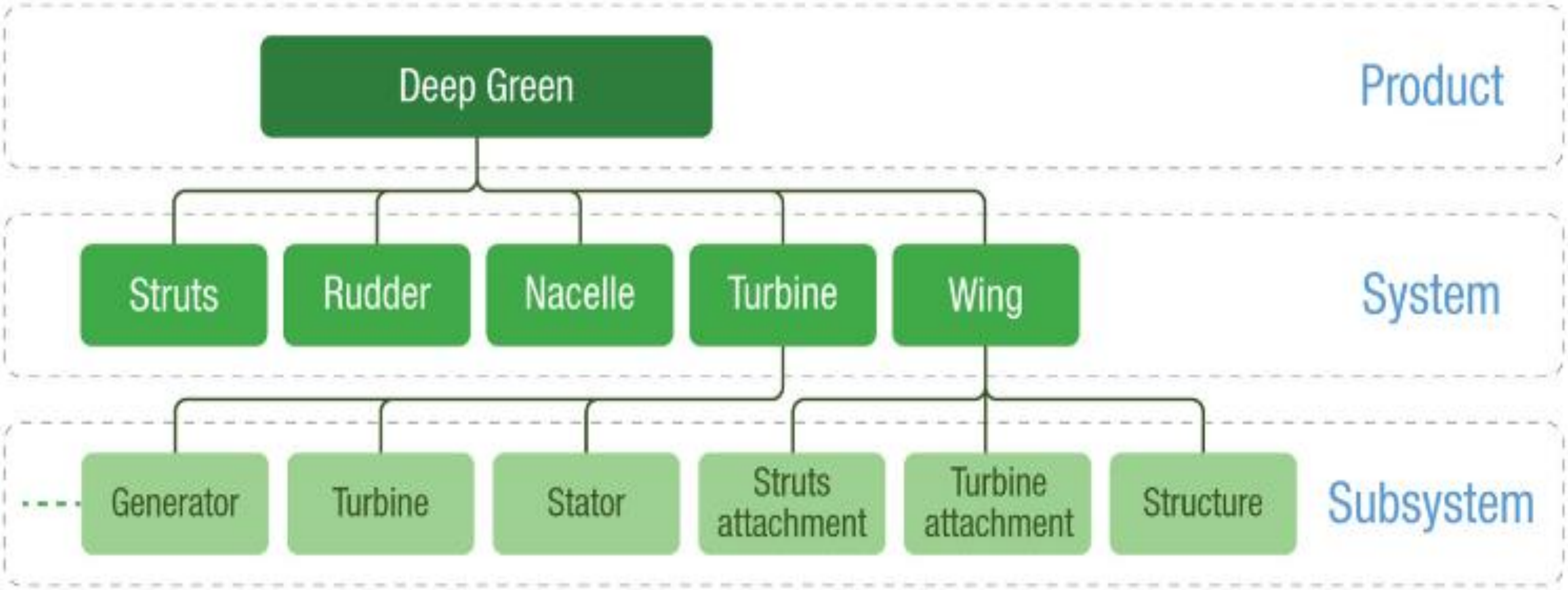
Deep Green – A tidal water power plant





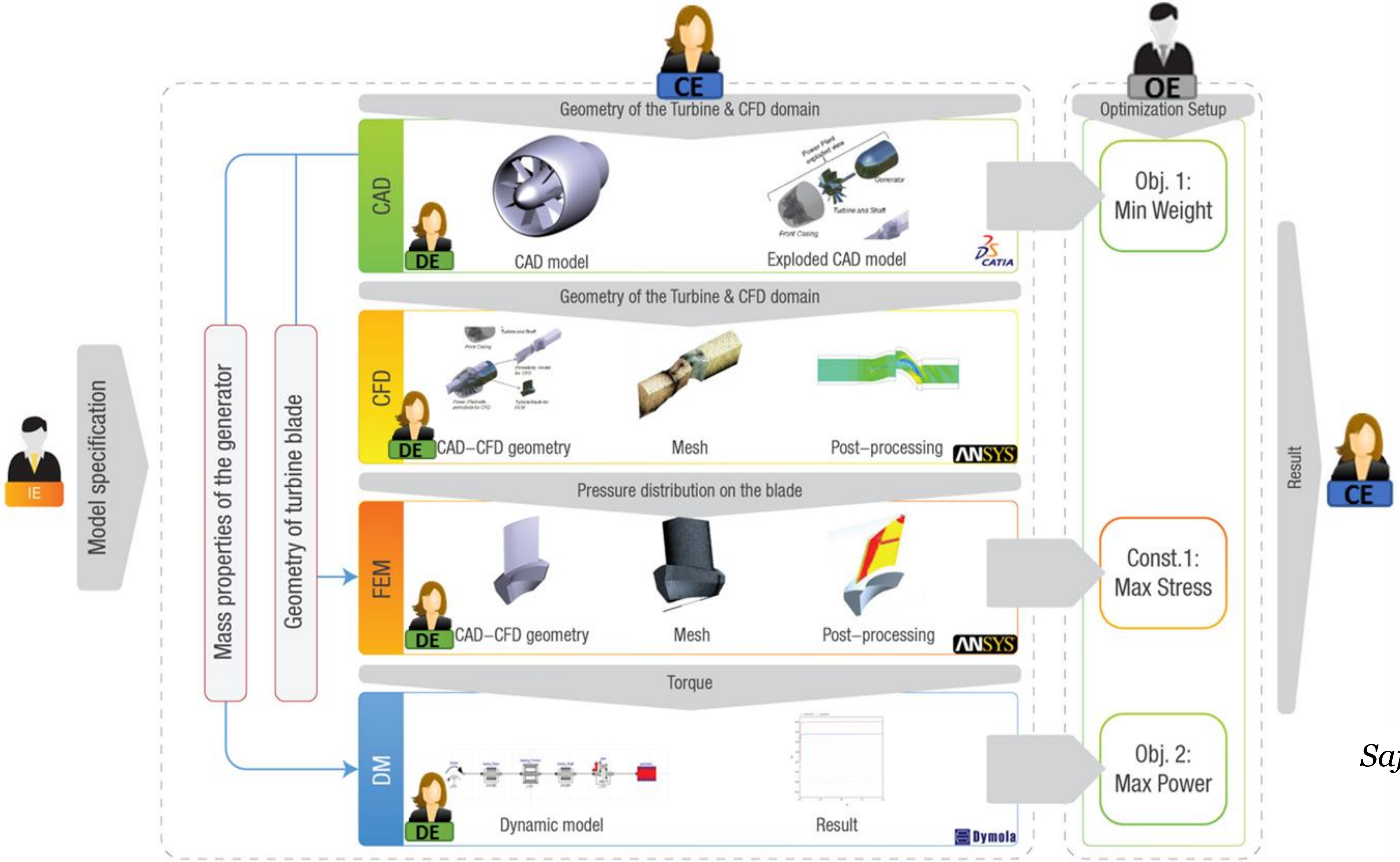
www.minesto.com

Deep Green – System decomposition



Safavi, 2016

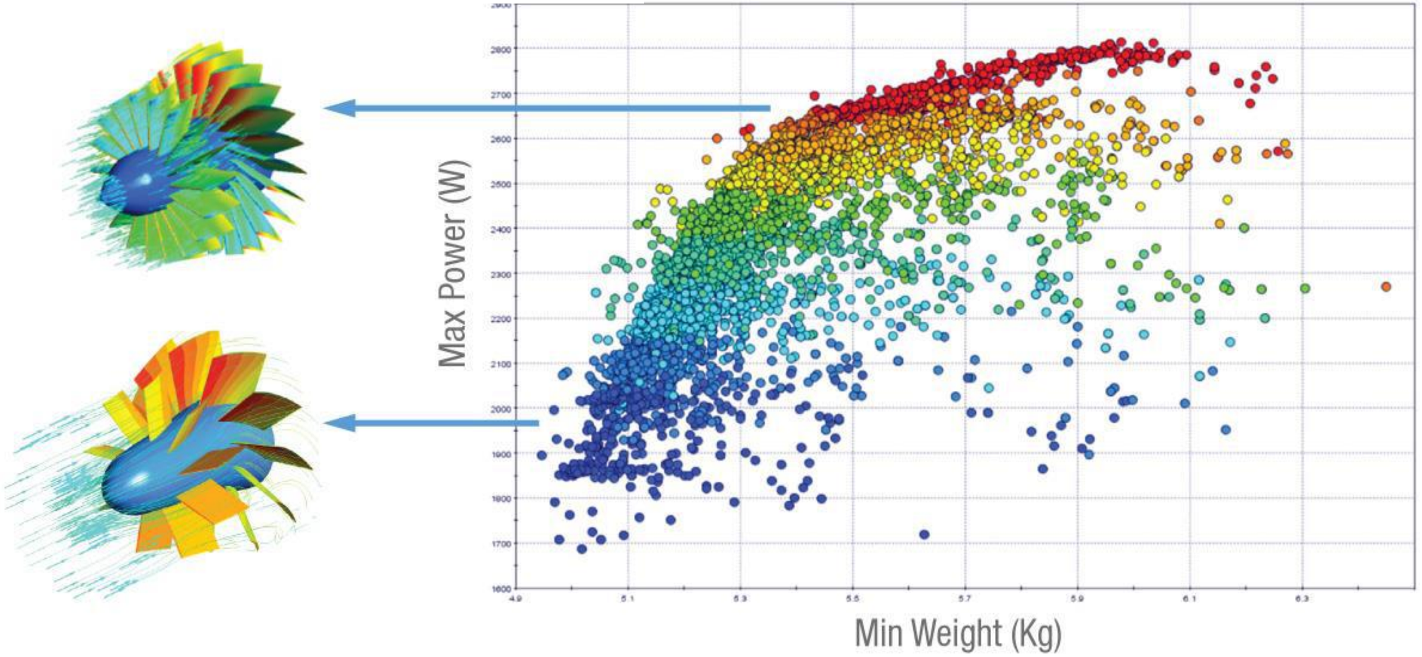
Deep Green – MDO framework



Safavi, 2016

Deep Green – problem and solutions

Optimization variable (x_j)	Lower band (x^L_j)	Upper band (x^U_j)	Unit
Generator type	1	10	–
Rotor thickness	0.4	1.3	cm
Rotor angle	6	11	Degree
Rotor diameter	22.5	27.5	cm
Stator thickness	0.6	1.5	cm
Stator angle	22	32	Degree
Number of blades	9	22	–



Design of an UAV

UAV design specifications

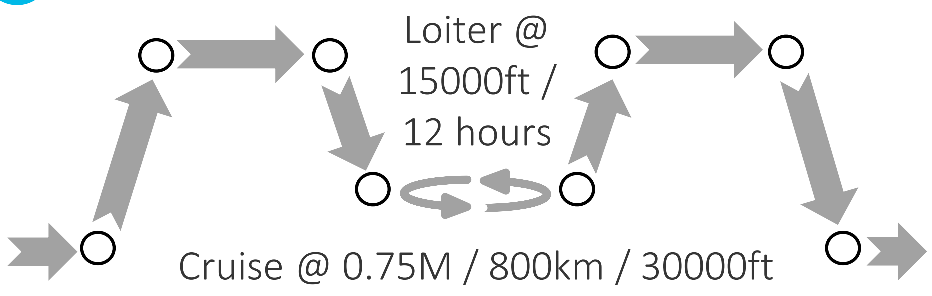
- Develop a surveillance UAV
- Design requirements
  - Long-endurance
  - Medium-range
  - High-altitude surveillance
  - Low-observability
- General characteristics
  - Hexagonal fuselage
  - V-shaped stabilizer
  - Turbofan engine

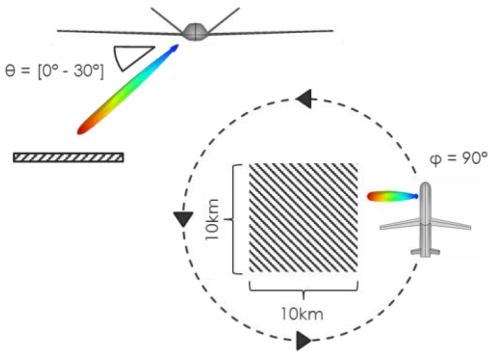
Papageorgiou et al., 2017

UAV Mission specifications

- Flight profile
  - A hypothetical mission
- Surveillance scenario
  - One specific direction
- Radar detection
  - Two threat sectors

1





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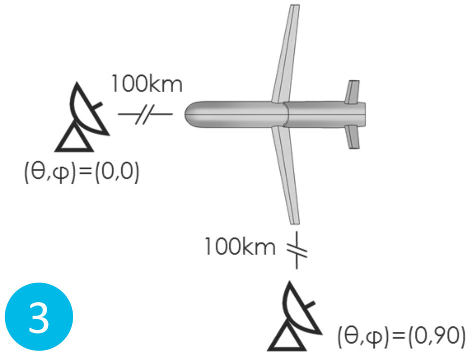

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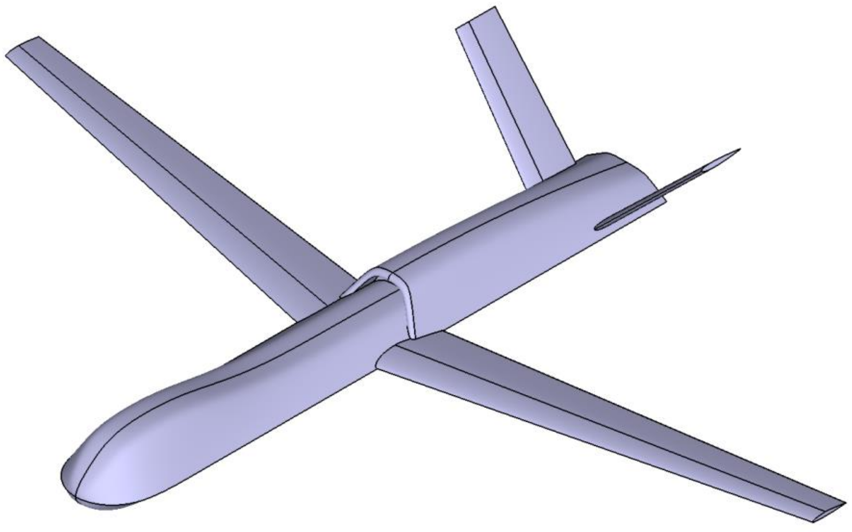
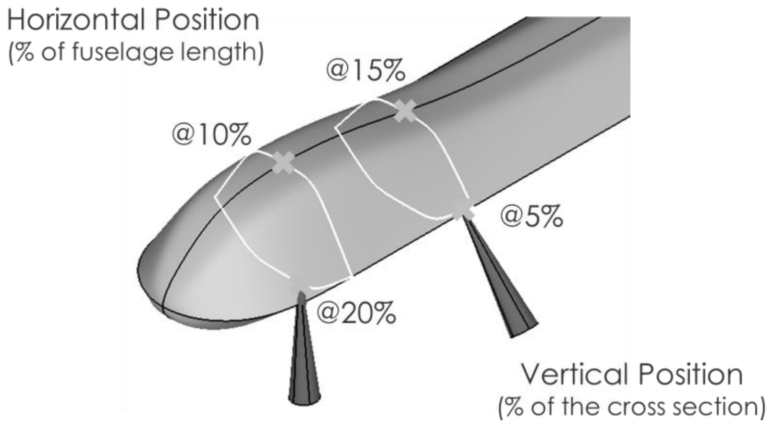
Papageorgiou et al., 2017

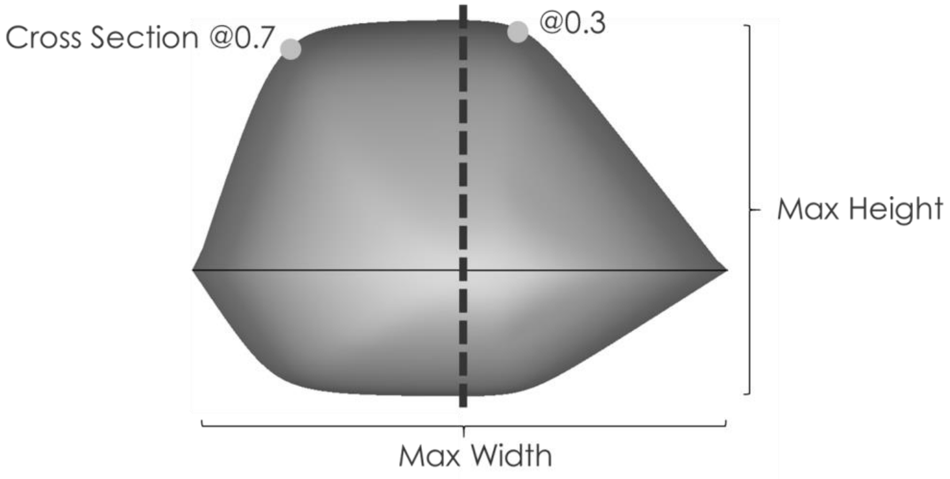
Framework structure

- Geometry model
  - CATIA V5-6R2014

Weight / Aero
Radar / Sensor



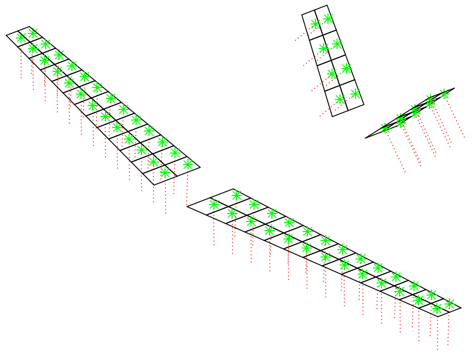




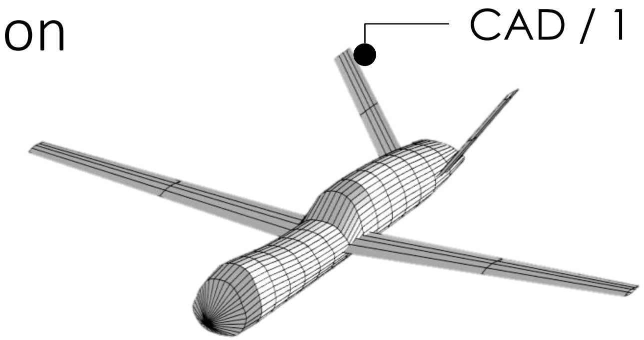
Papageorgiou et al., 2017

Framework structure

- Aerodynamics / Stability / Balance
  - TORNADO
  - Vortex Lattice Method
  - Empirical stability equations
  - MATLAB



- Weight estimation / Mission simulation
  - DIBA
  - Empirical sizing equations
  - Propulsion specifications
  - MATLAB



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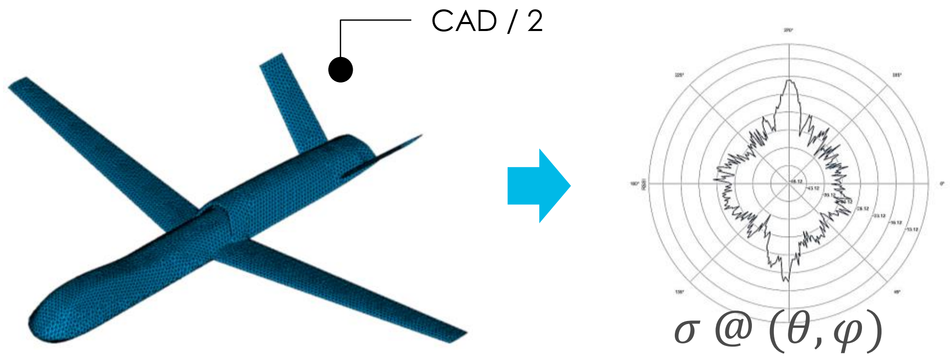
Framework structure

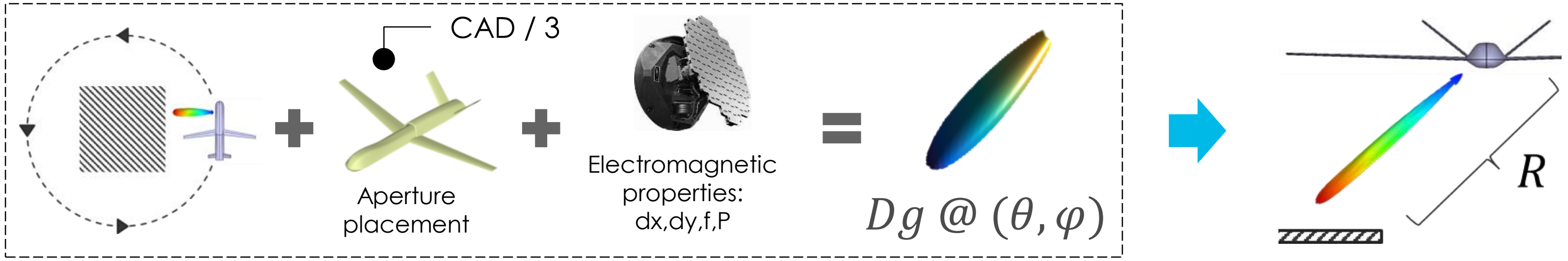
➢ Radar signature

- GRECO by UPC
- Physical Optics
- Monostatic



➢ Sensor performance

- MATLAB / Empirical electromagnetic equations



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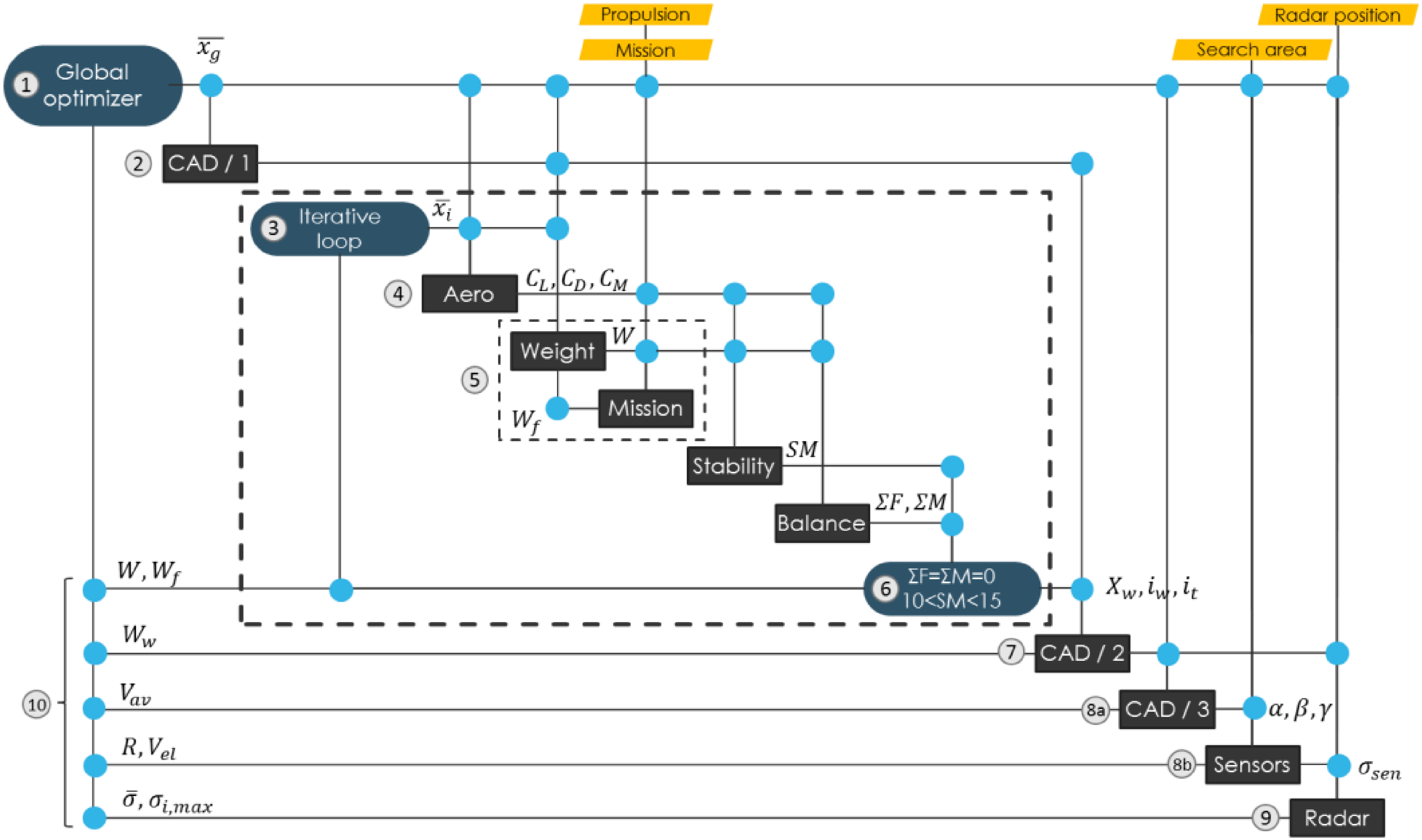
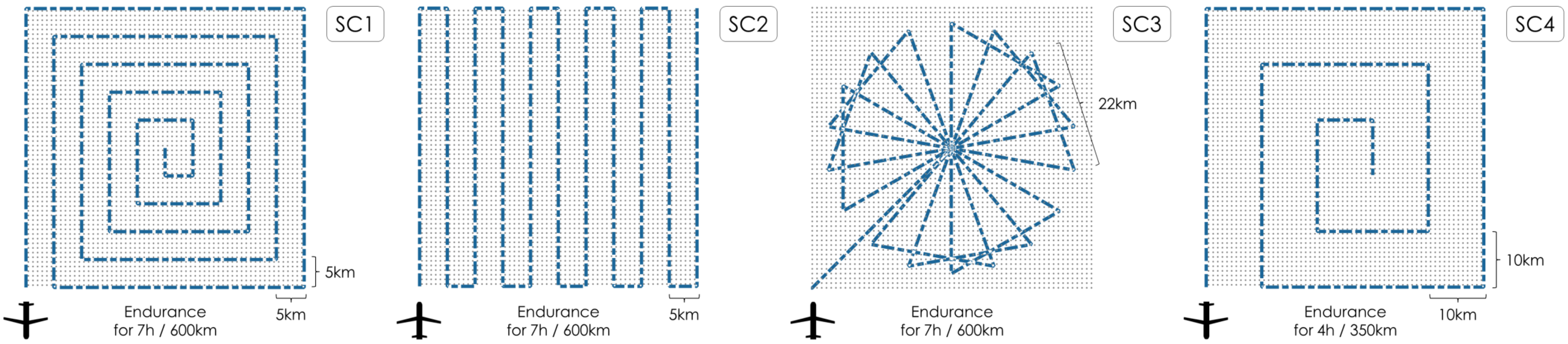
MDO framework



UAV user requirements – different search scenarios



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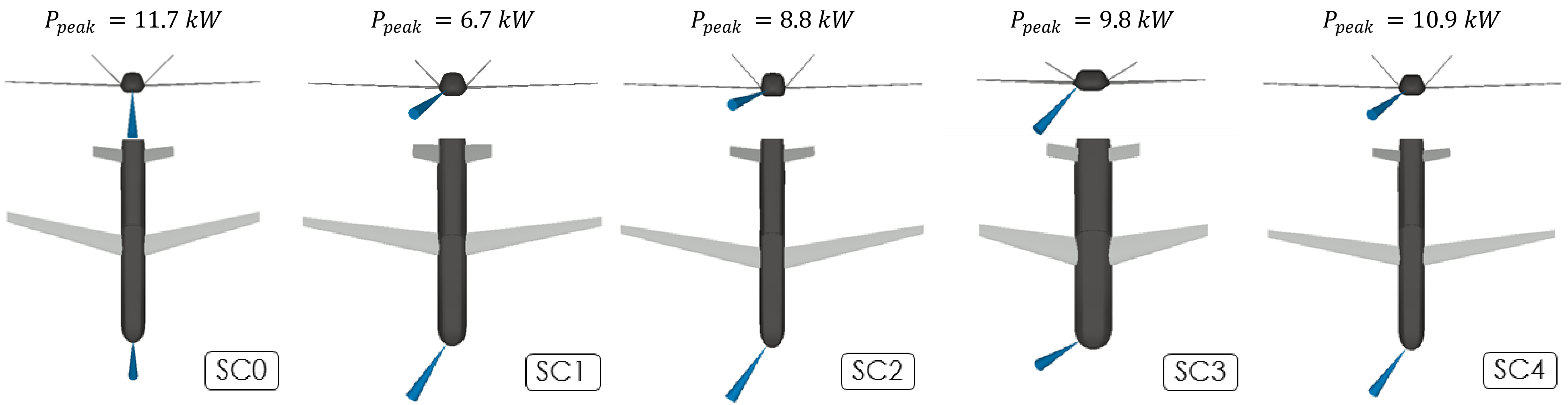
UAV - MDO results



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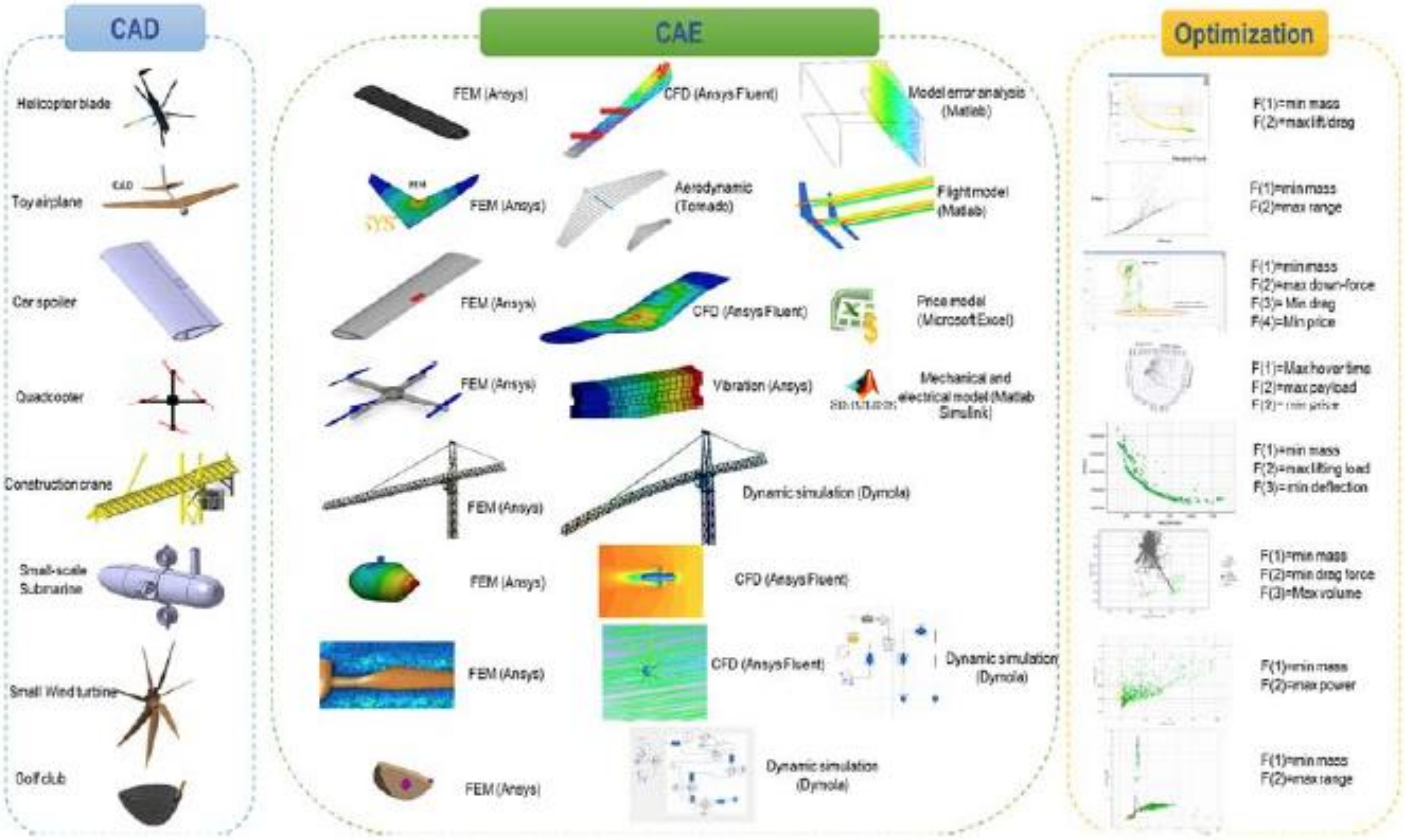
Concluding remarks

Bridging the educational gap – MDO teaching



MDO enablers – What we need to master

- Define requirements
  - Use cases, scenarios, IoT etc.
- Representations of search space
  - Model flexibility, model connectivity etc.?
- Optimization problem formulation
  - Objectives, constraints, variables
  - Decomposition and solutions strategies
- Computational efficiency
  - Meta-models, parallel computing, etc.
- Organizational support
  - Integration in the product development process
  - Define roles, tasks and responsibilities

Questions?

Never send a human to do a machine's job

/Agent Smith (Matrix)

Acknowledgments

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