CAD-centric multidisciplinary optimization for industrial aeronautics design

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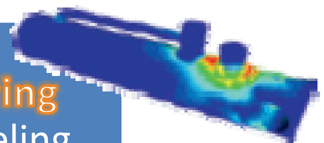
Aim & Outline

- **Aim**
  - Present some “real” applications of multi-objective multidisciplinary optimization for complex design problems in aeronautics

- **Outline**
  - Short presentation of the Minamo optimization platform
  - Example 1: design of counter rotating open rotors (aeroacoustics)
  - Example 2: design of composite structural parts (cost, manufacturing)

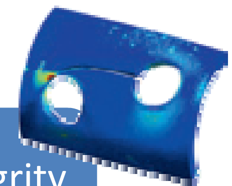
Who we are ?

R&T private company focused on simulation and modelling



Manufacturing process modeling

Project Management



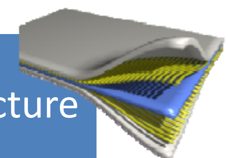
Structural integrity analysis

High Performance Computing

On demand

R&T

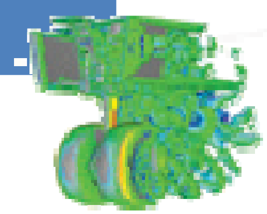
Consulting



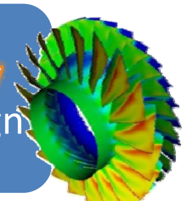
Composite structure design

Multidisciplinary optimization

Aerodynamic flow analysis



Turbomachinery aerodynamic design



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ALSTOM

AIRBUS

RENAULT

AGC

ArcelorMittal

PSA PEUGEOT CITROËN

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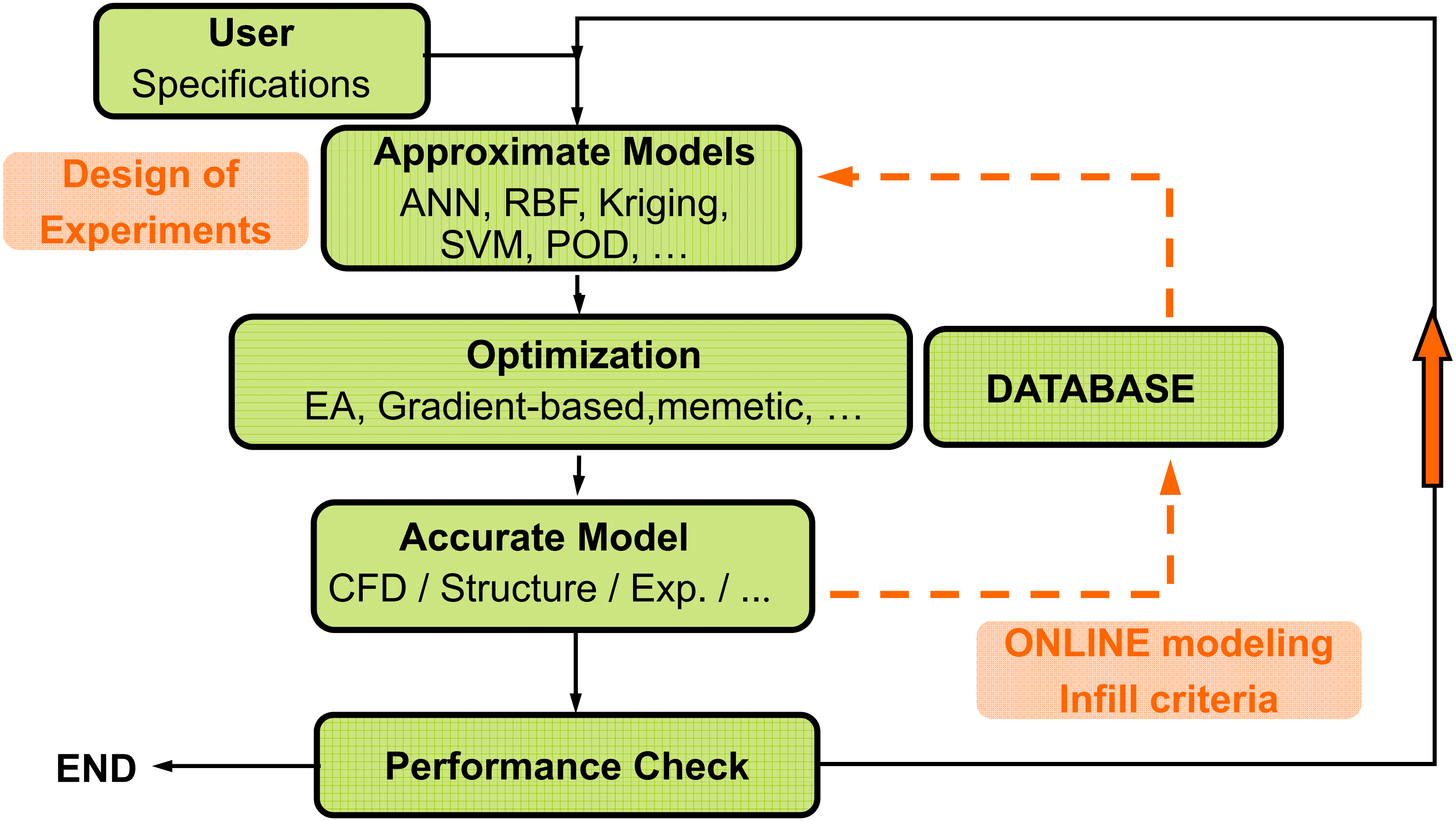
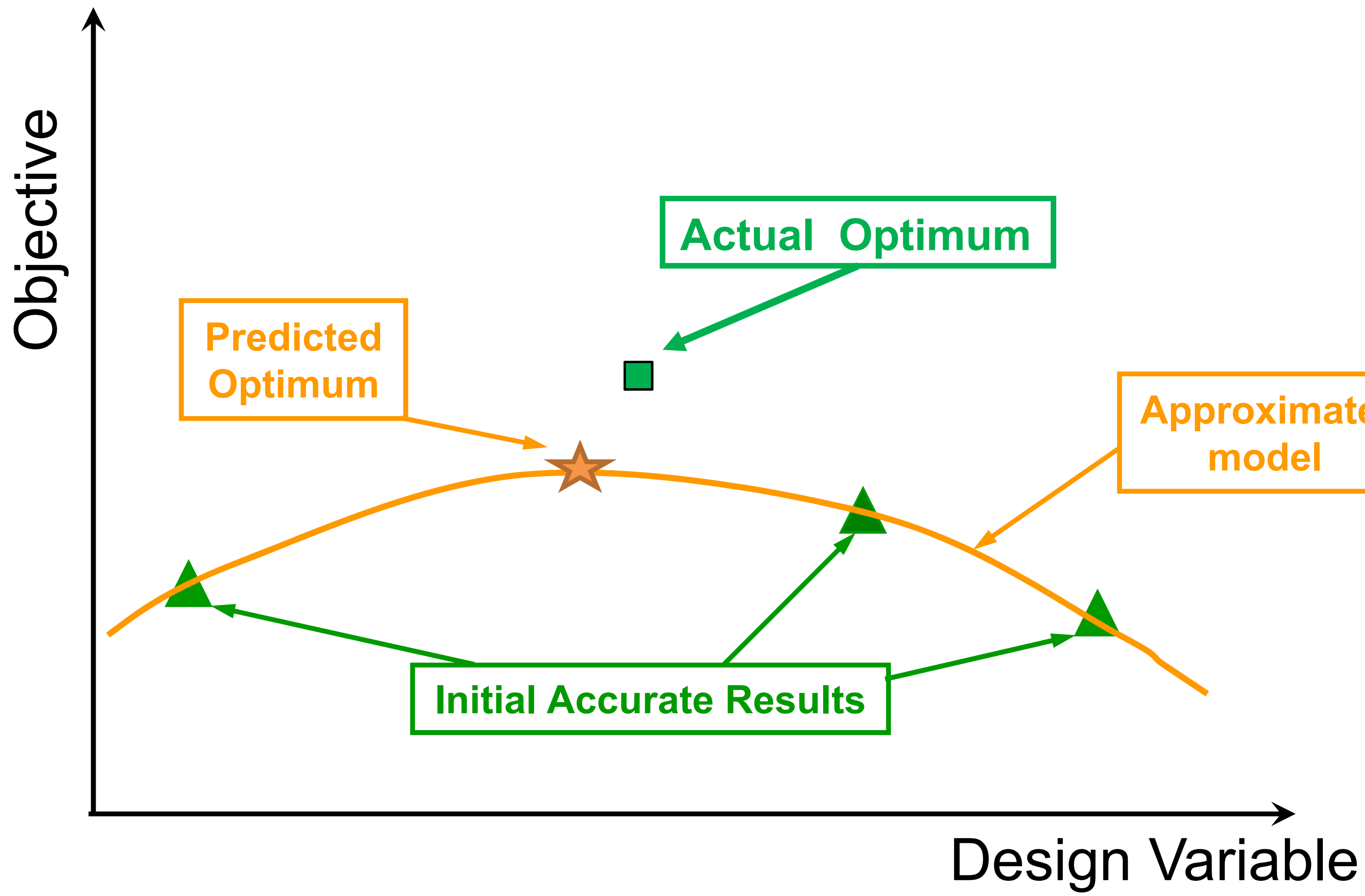
Minamo basics

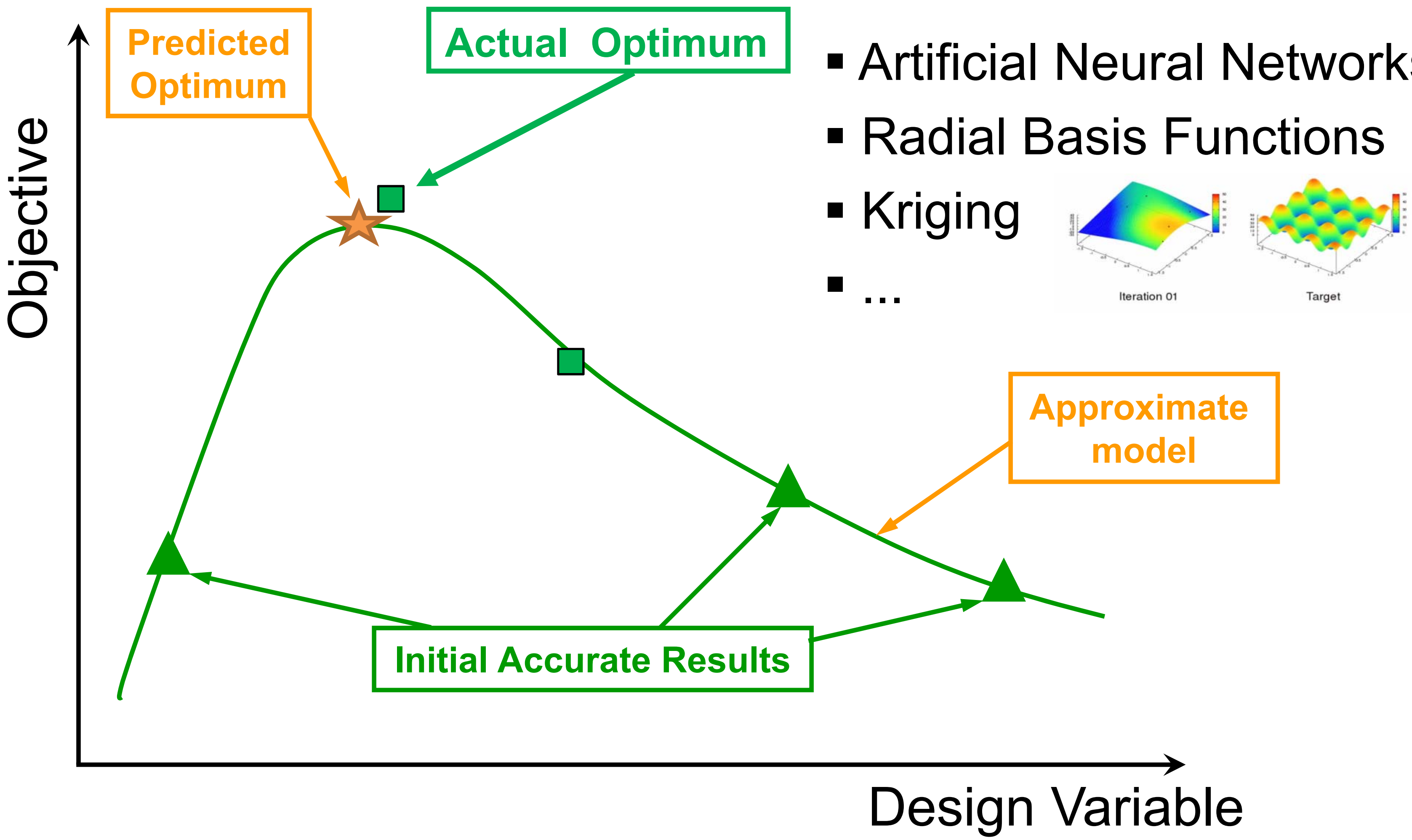
Surrogate Based Optimization



Surrogate based optimization



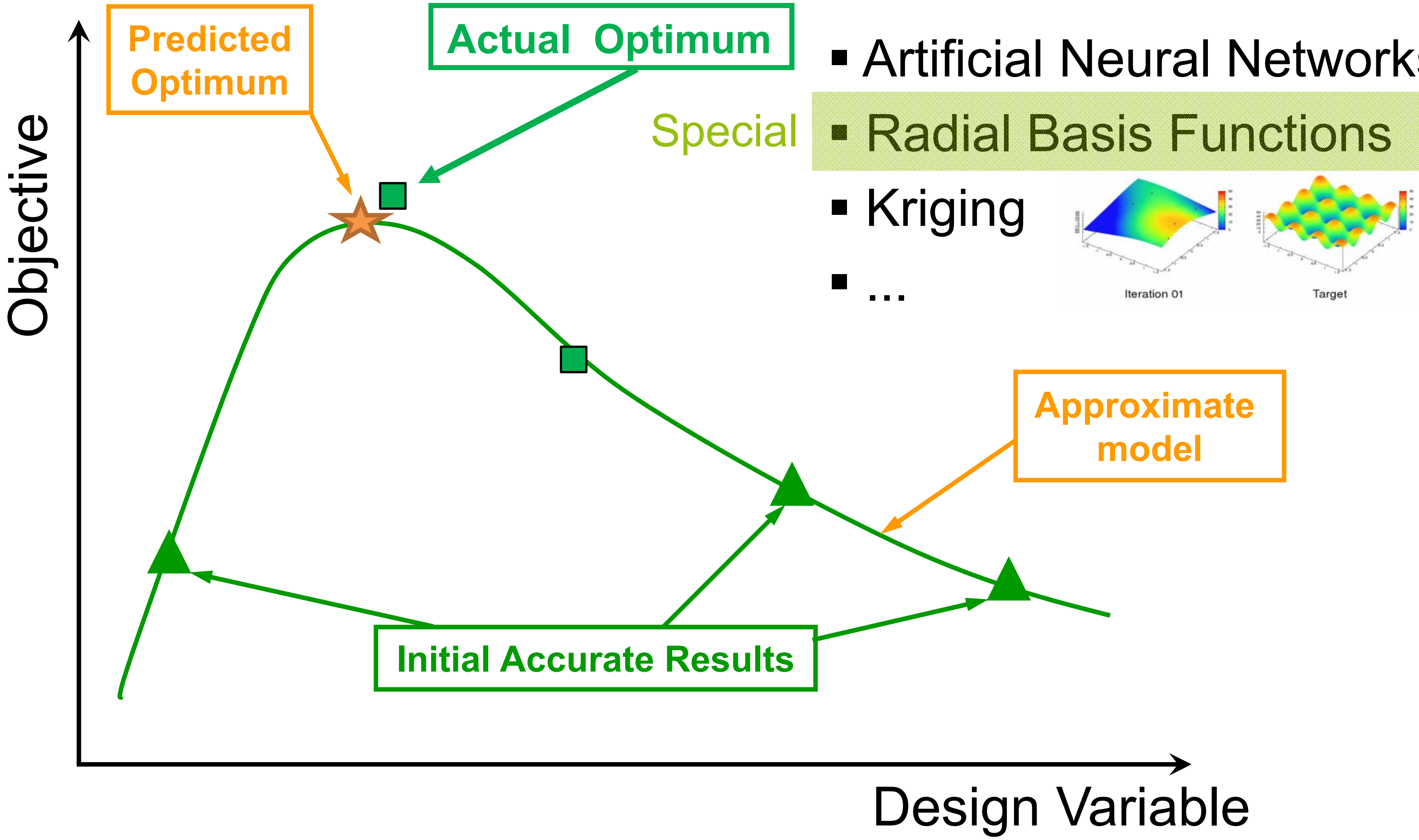
Surrogate based optimization



- Artificial Neural Networks
- Radial Basis Functions
- Kriging
- ...

Surrogate based optimization

Special
- Artificial Neural Networks
- Radial Basis Functions
- Kriging
- …

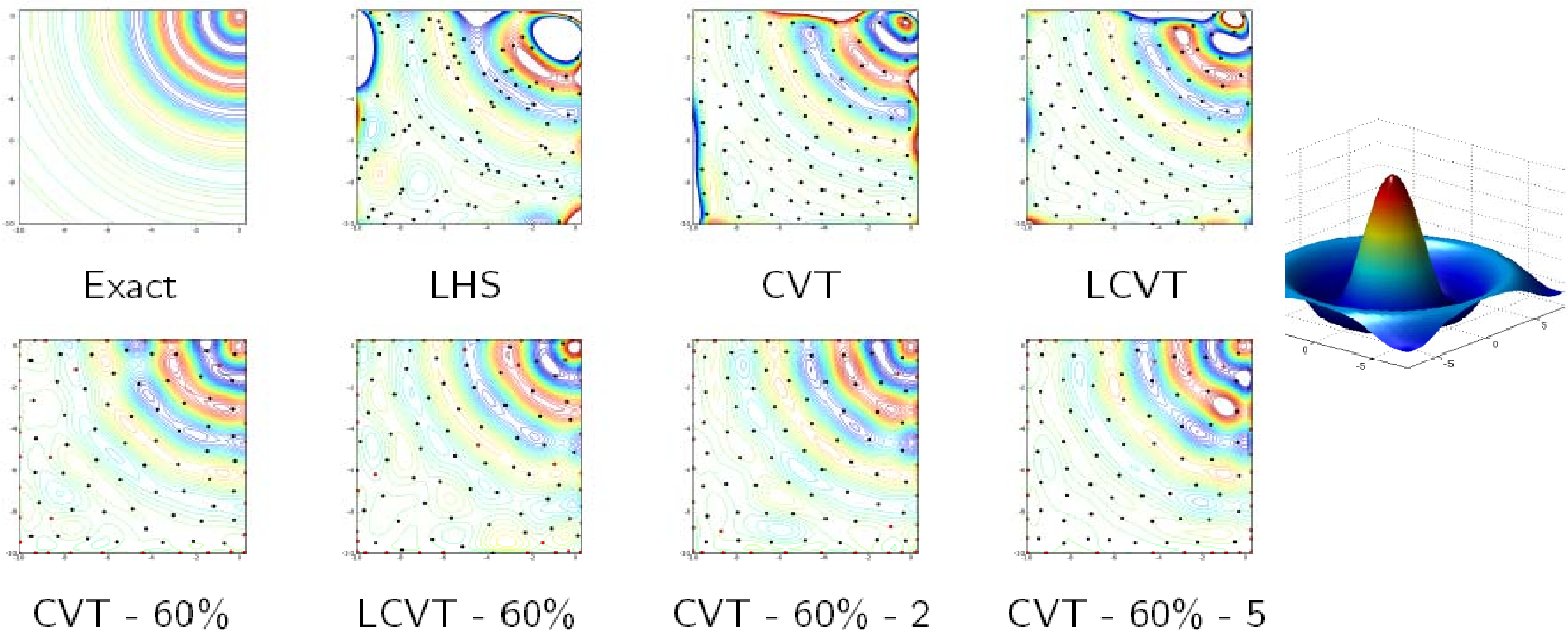


In a surrogate model approach, the devil's in the details:

- What points do you sample in building the approximation ?
- What approximation method do you employ ?
- How do you manage the approximation model(s) ?
- How do you use the approximation to suggest new, improved designs ?
- How do you use the approximations to explore tradeoffs between objectives ?

Derivative free optimization with Minamo

- **Illustration of adaptive sampling capability**



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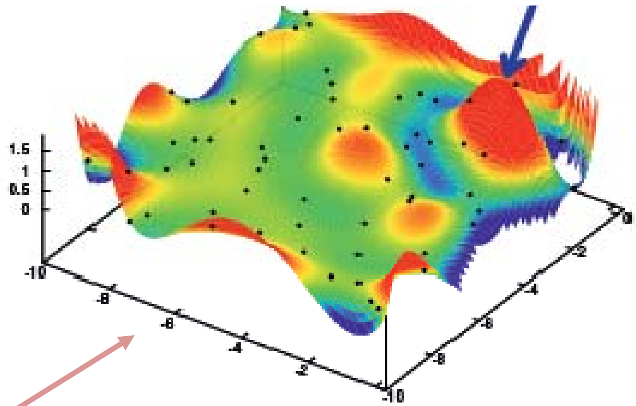
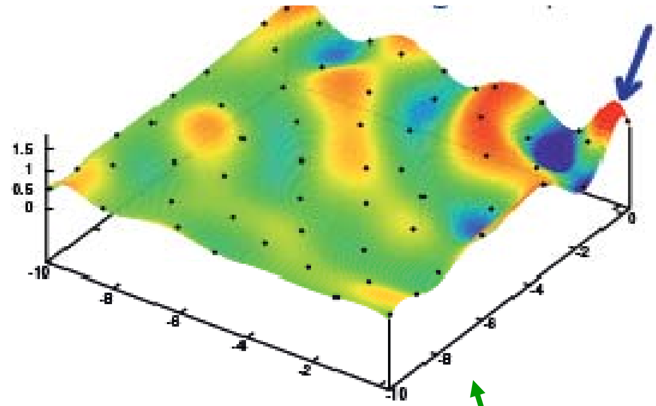
Efficient Design Exploration

Candle function

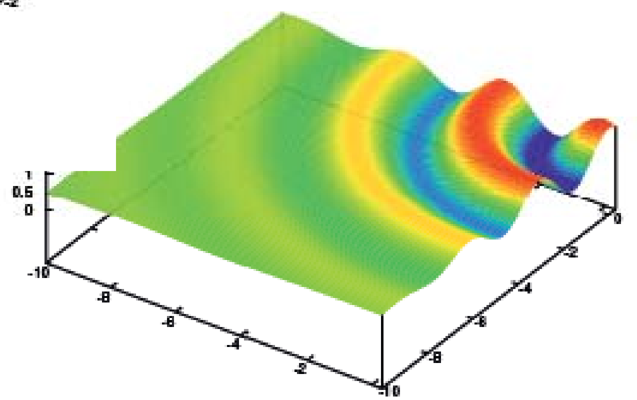
Misplaced optimum



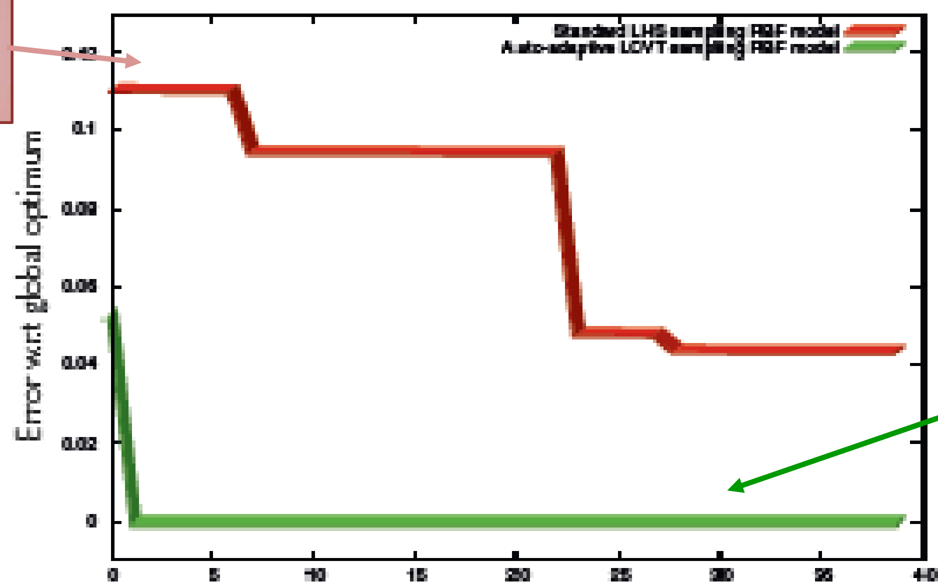
Global optimum



Exact solution



Standard LHS sampling



Auto-adaptive LCVT sampling

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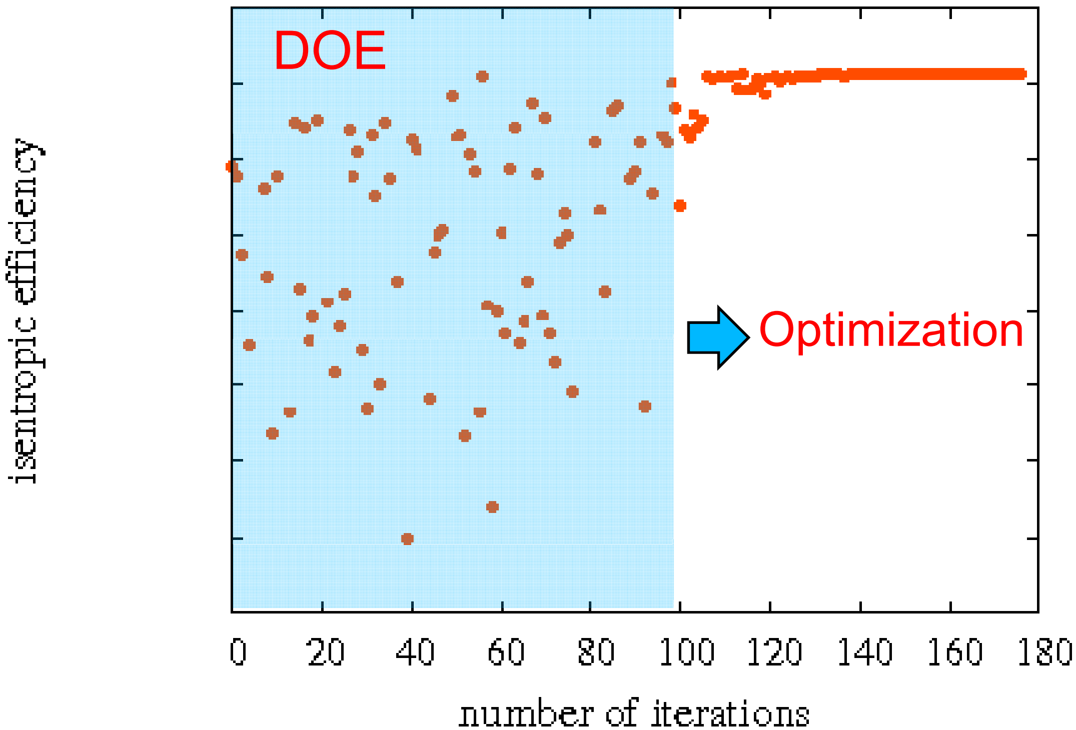
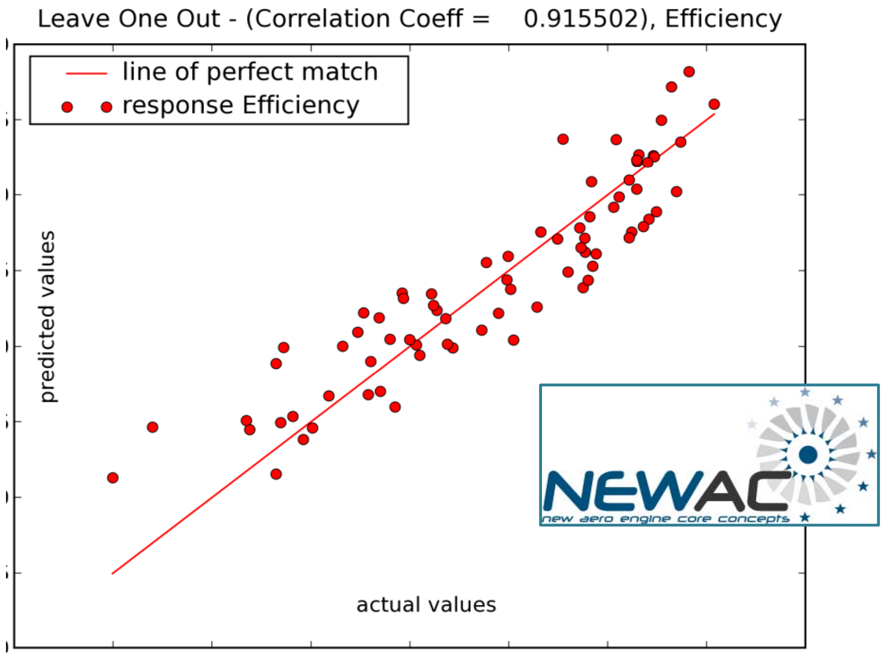
Monitoring/Reliability
Leave-One-Out (Open gap/Stall point)





Large DoE scatter - Stabilization after about 50 design iterations: 2 different promising design families pointed out, satisfying the manufacturing constraints

LOO Reliability Assessment:

Isentropic efficiency correlation coefficient

0.915502 (DoE) ⇨ **0.9685** (optimization)

ANOVA – Sobol indices

First order sensitivities and interaction volume (if required higher order sensitivities) quantification

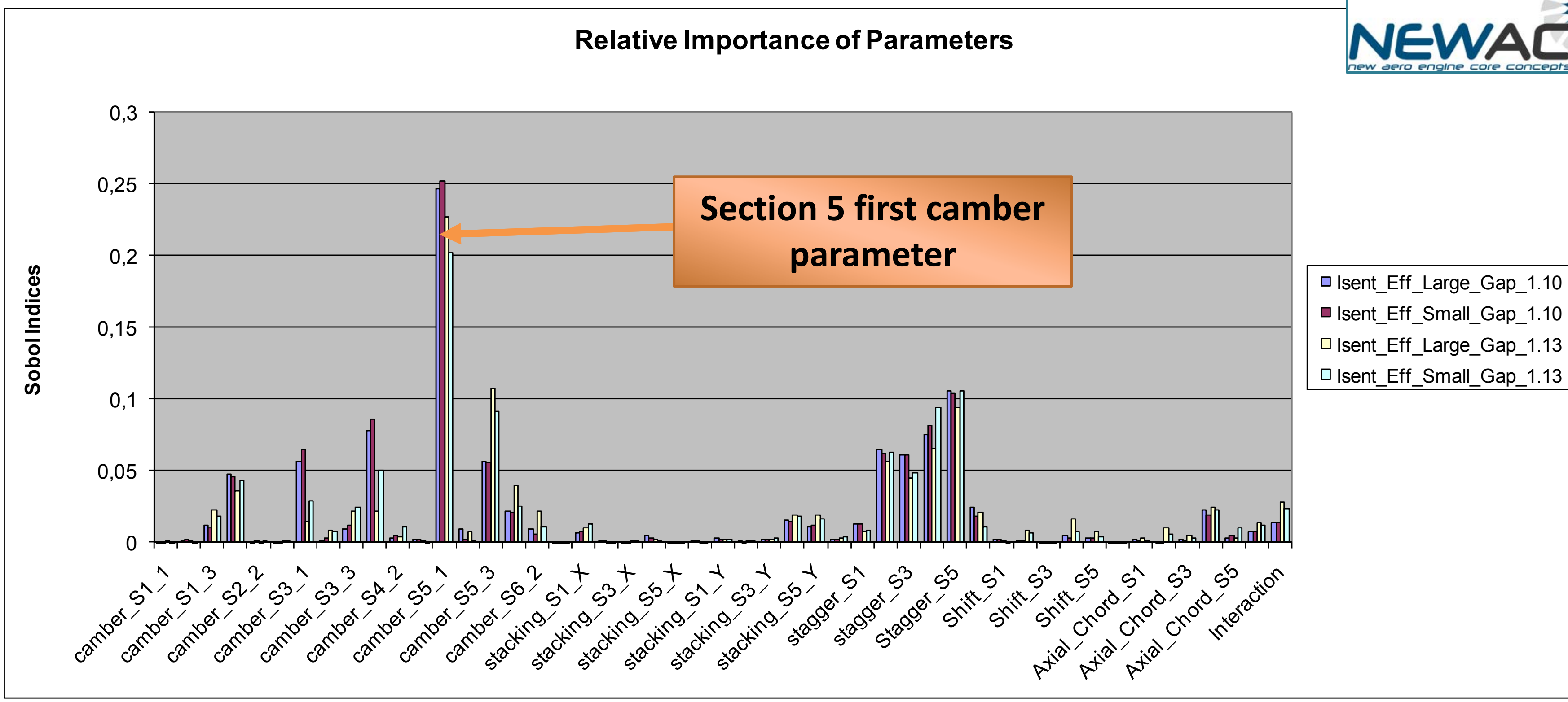
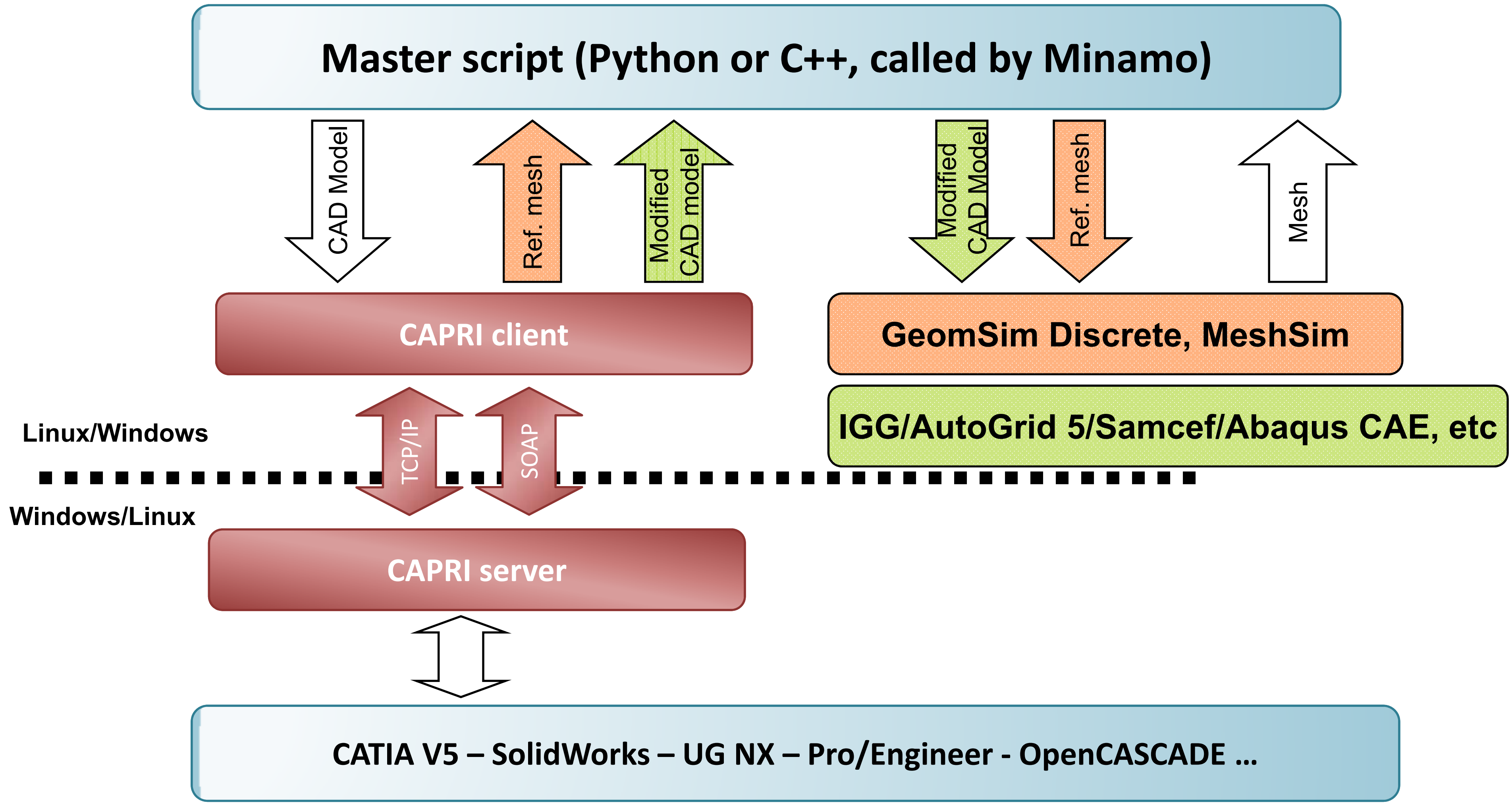


Illustration on NEWAC optimization accounting for engine wear

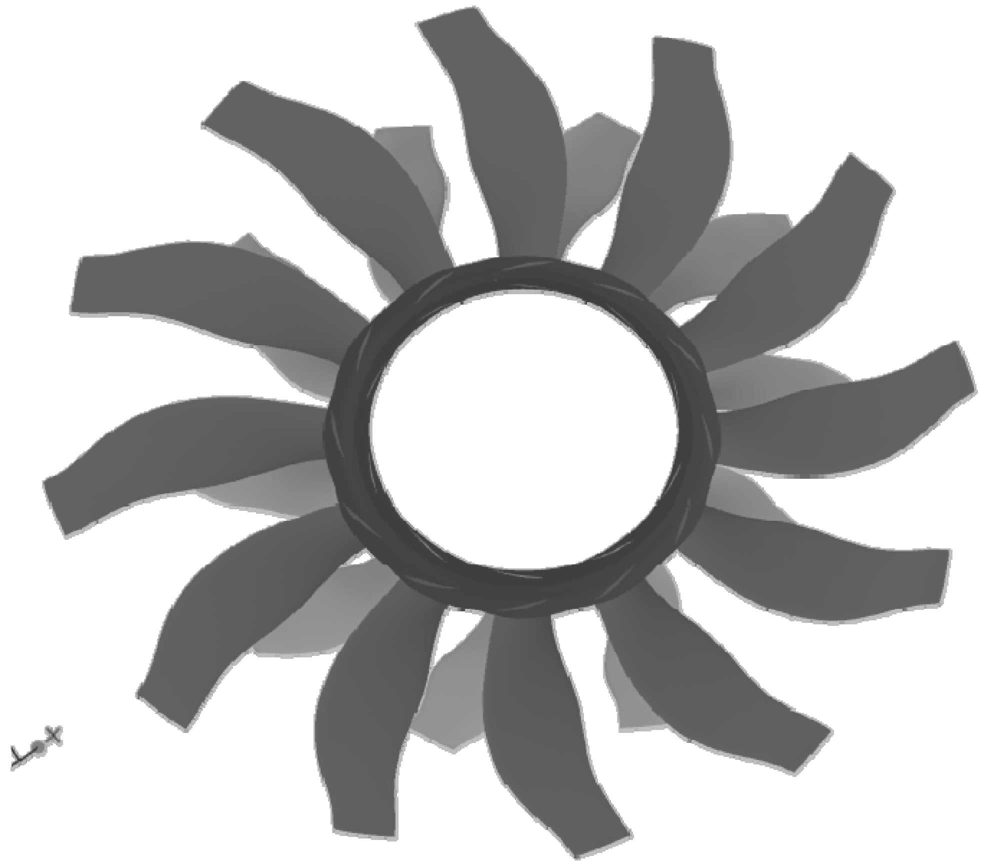
Direct CAD access CATIA – CAPRI – mesher



Summary of Minamo Features

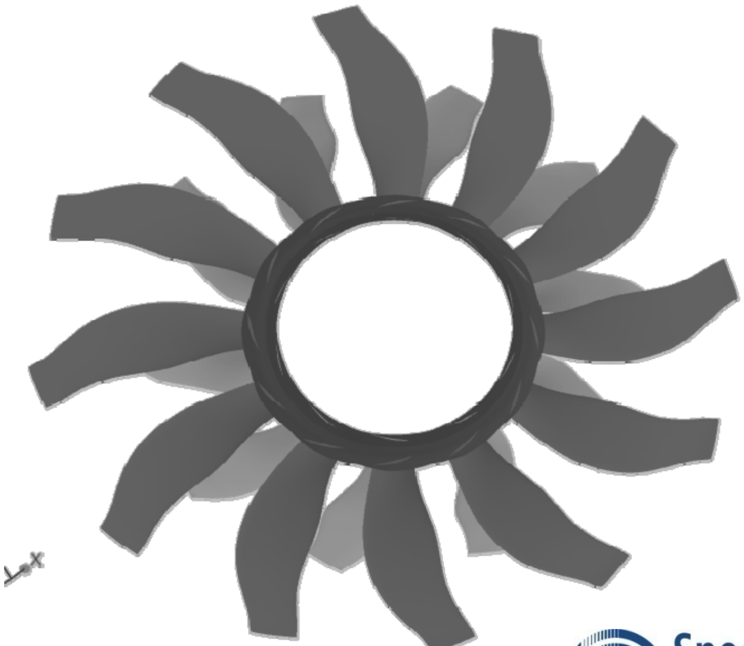
- Mono- and multi-objective evolutionary algorithms, including memetic approaches
- Online surrogates approach
- Space fill and auto-adaptive DoE (LHS, CVT, LCVT, …)
- Efficient adaptive nonlinear global and local models (ANN, RBFN, Kriging, SVM, …)
- Response surfaces reliability through leave-k-out cross-validation
- Constraints activity interactive monitoring
- Quantitative Variance Analysis tool (ANOVA): Sobol sensitivity indices estimation
- Data mining capabilities for efficient multi-criteria decision making (self organizing maps, …)
- Simulation coupling through Python scripting
- Native and neutral CAD access
- Available in standalone version or as engine plug-in in other software (Optimus)

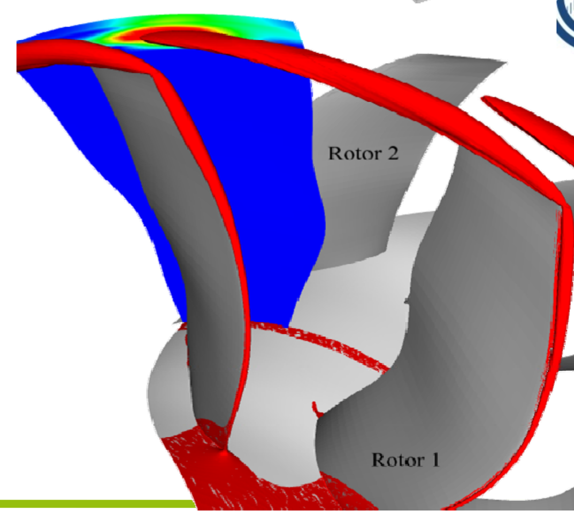
Example 1: Design of Counter-Rotating Open Rotors



Aeromechanical Optimization of a Counter-Rotating Open Rotor (CROR)

- **Open Rotor Advanced Concept Studies**
  - Potential to meet drastic fuel burn decrease for future passengers aircraft at horizon > 2020
  - Challenges:
    - Noise mitigation while ensuring high efficiency



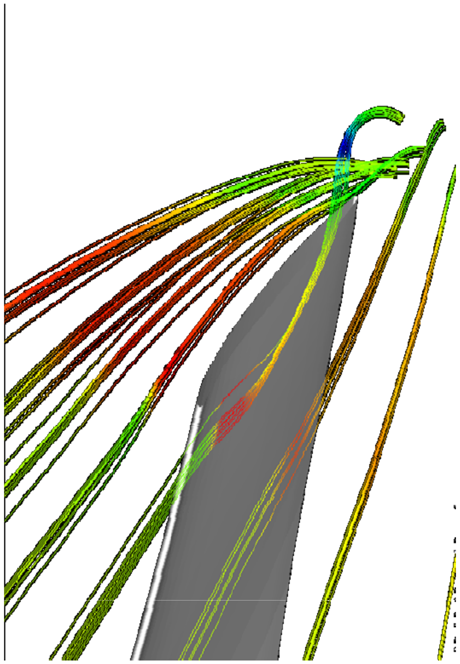


Snecma Groupe SAFRAN

Optimization Specification

- **Objective function:**
  - **Maximization of global efficiency @ TOC**
  - **Minimization of acoustic level @ TO**
- **Constraints:**
  - **Aerodynamic constraints:**
    - Thrust requirements @ TOC and TO
    - Torque split @ TOC and TO (DD architecture)
    - Streamlines contraction/R1 tip vortex
  - **Mechanical constraints**
    - Max VM stress/ linear FE, rig-scale
    - Simplified flutter criterion
  - **Geometric constraints/feasibilitiy:**
    - LE/TE thickness, max thickness, reverse mode,
    - LE curvature change criterion, curvilinear length of TE, CG position

=> About 80 constraints to satisfy



- **RPM_{R1}= RPM_{R2}**
- **Variable blade re-staggering (including between both OPs)**
- **Clipping of rotor 2 is fixed, no contouring modification**
- **Failed or unstable simulations handled by a success switch**

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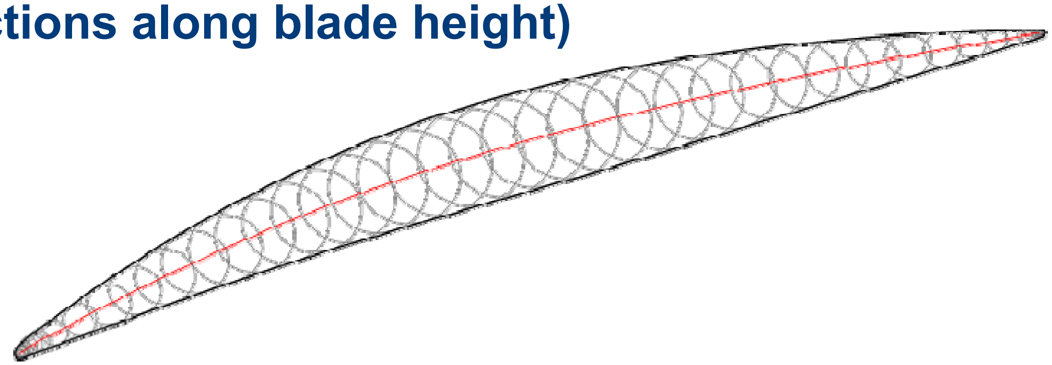
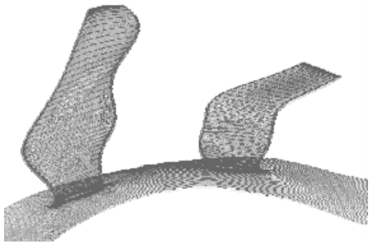
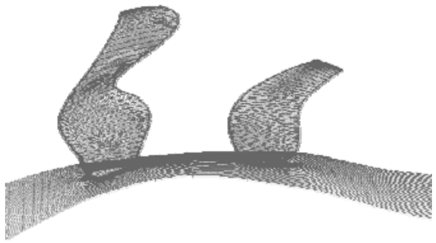
- **Profile shape** (6 equidistant sections along blade height)
  - Maximum thickness
  - Maximum thickness position
  - Chord length
  - Stagger angle
  - Skeleton angle at LE/TE



- **Stacking** (6 equidistant sections along blade height + 2 additional sections at 90 and 95%)
  - CG axial position
  - CG tangential position





- **Blade pitch angles**

  including variable delta restaggering between TOC and TO

⇨ 102 parameters conception space

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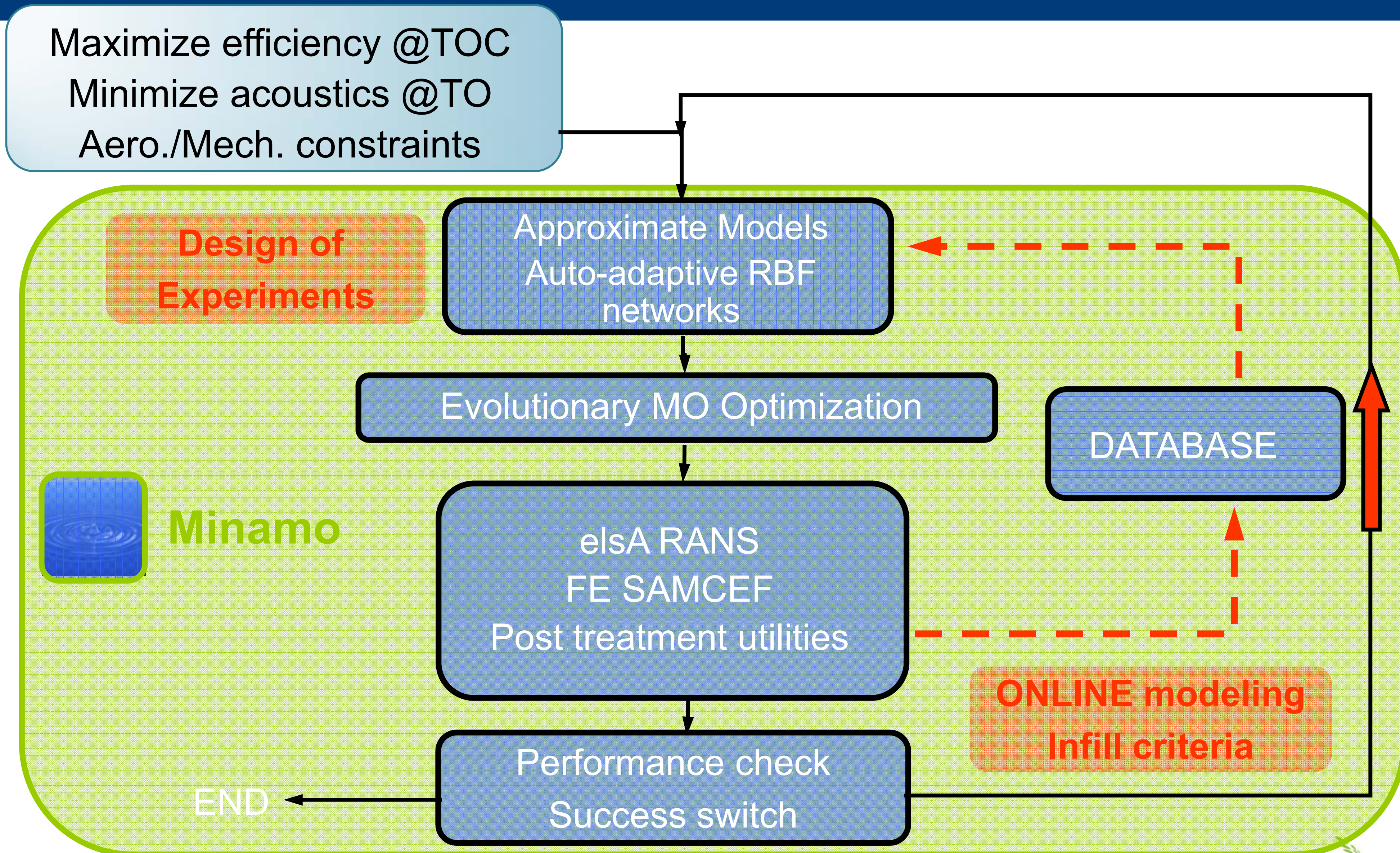
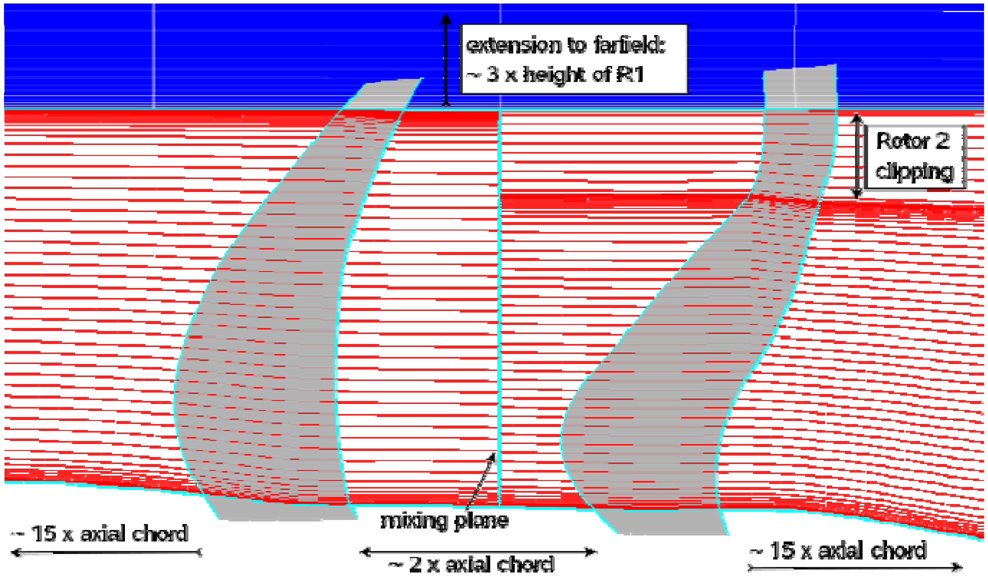
CROR Optimization Chain Setup

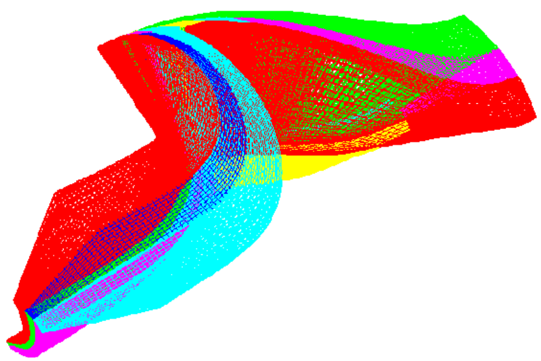


CROR CFD Setup

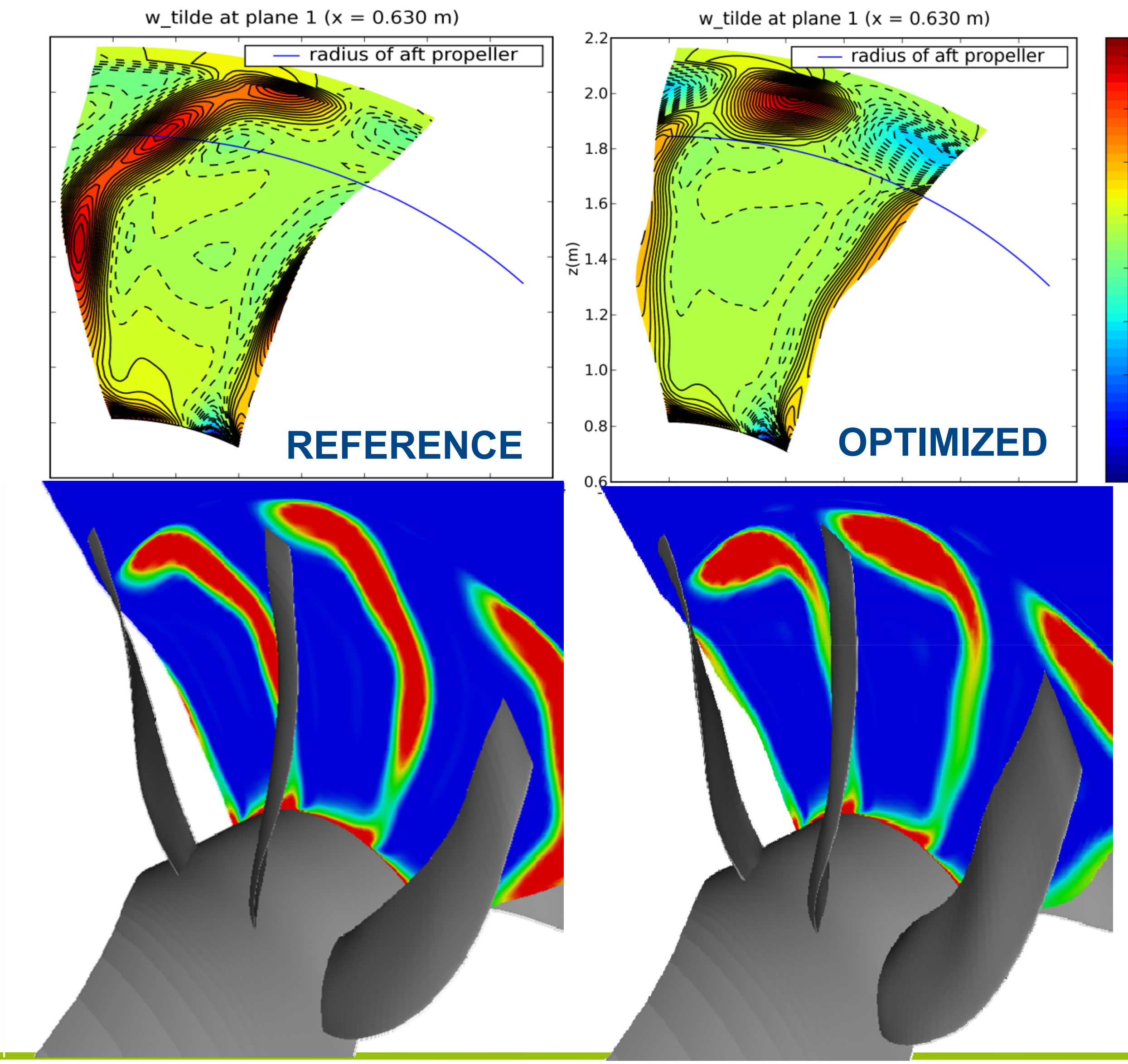
- **elsA (ONERA) RANS simulations with mixing plane**
  - **Absolute velocity formulation**
  - **Non reflecting farfield BCs**
  - **k-ω Wilcox turbulence model**
  - **Jameson's scheme**
  - **Full Multigrid (2 levels)**



- **Mesh convergence analysis** (~ 3 10^6 nodes)
  - **Cost functions convergence**
  - **Farfield boundaries positioning**
  - **Regeneration robustness assesssed through dedicated DoE**



Lessons Learned Phase 2
Acoustic cost function behaviour



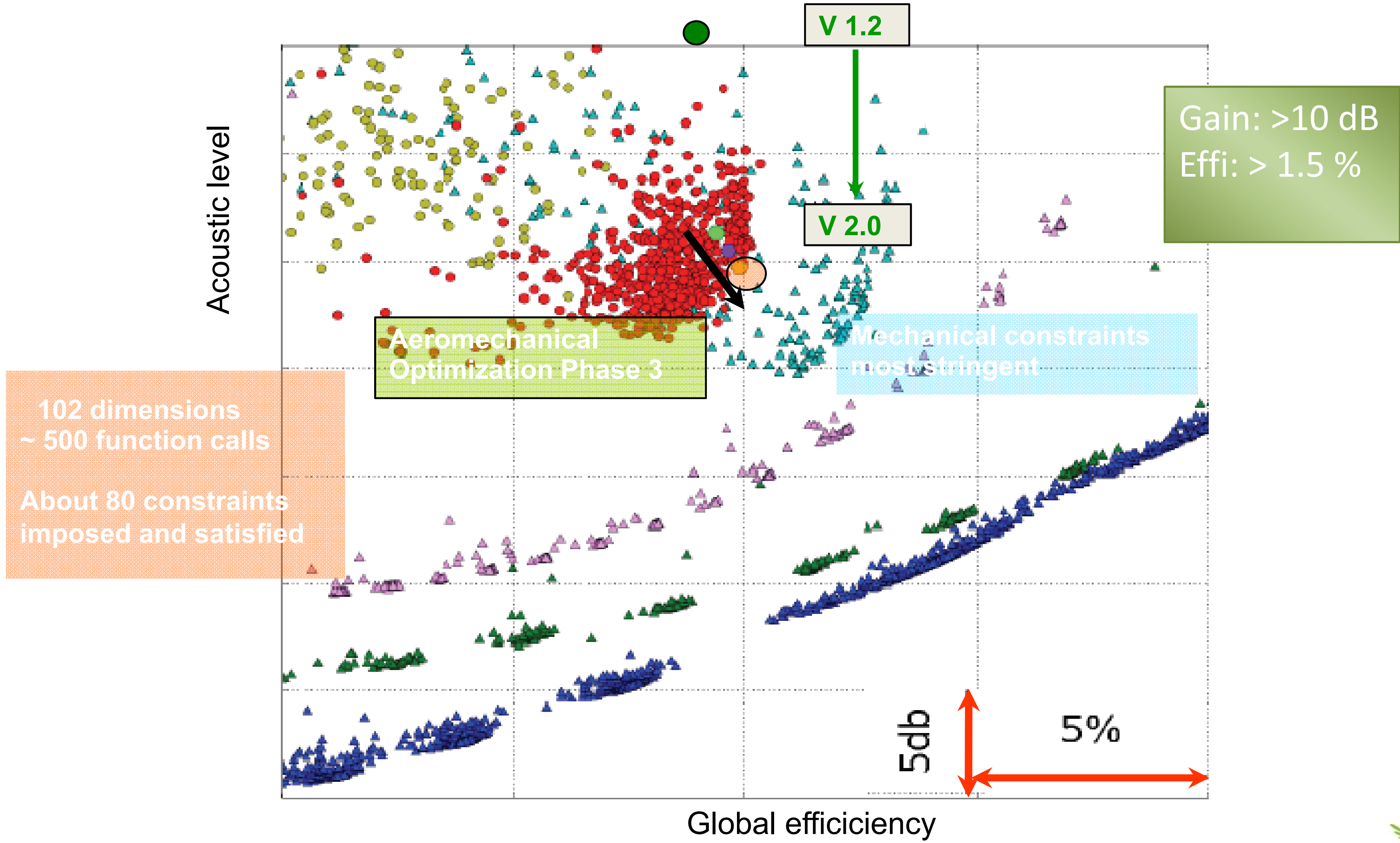
Acoustic criterion may be seen as "minimization of R1 wake, up to the height of R2"

$\hat{w}$ = projection of relative speed fluctuation on the normal to the mean flow

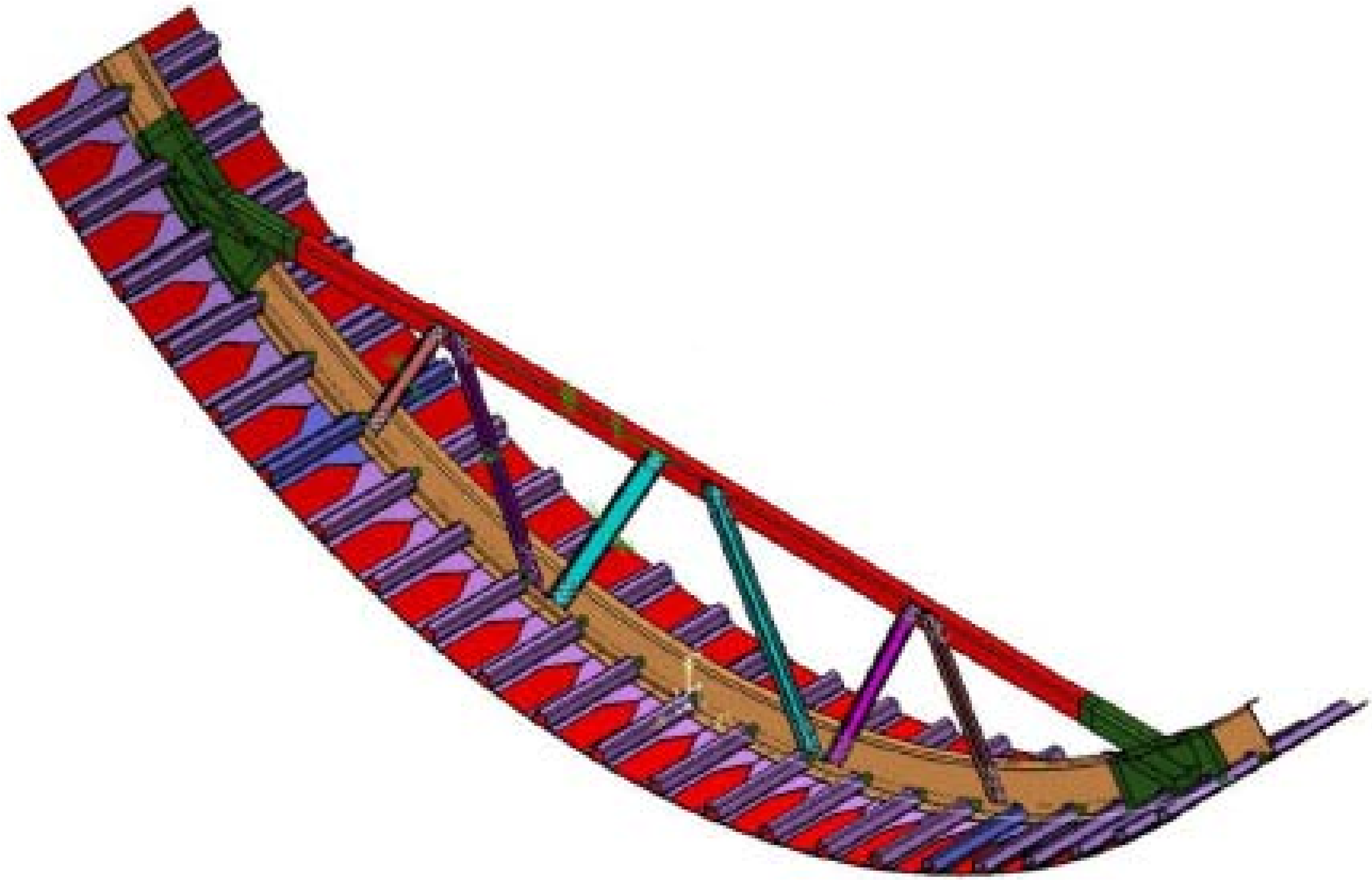
Wake of R1 reduced up to the height of R2

R1 tip vortex strengthened, but above R2 tip

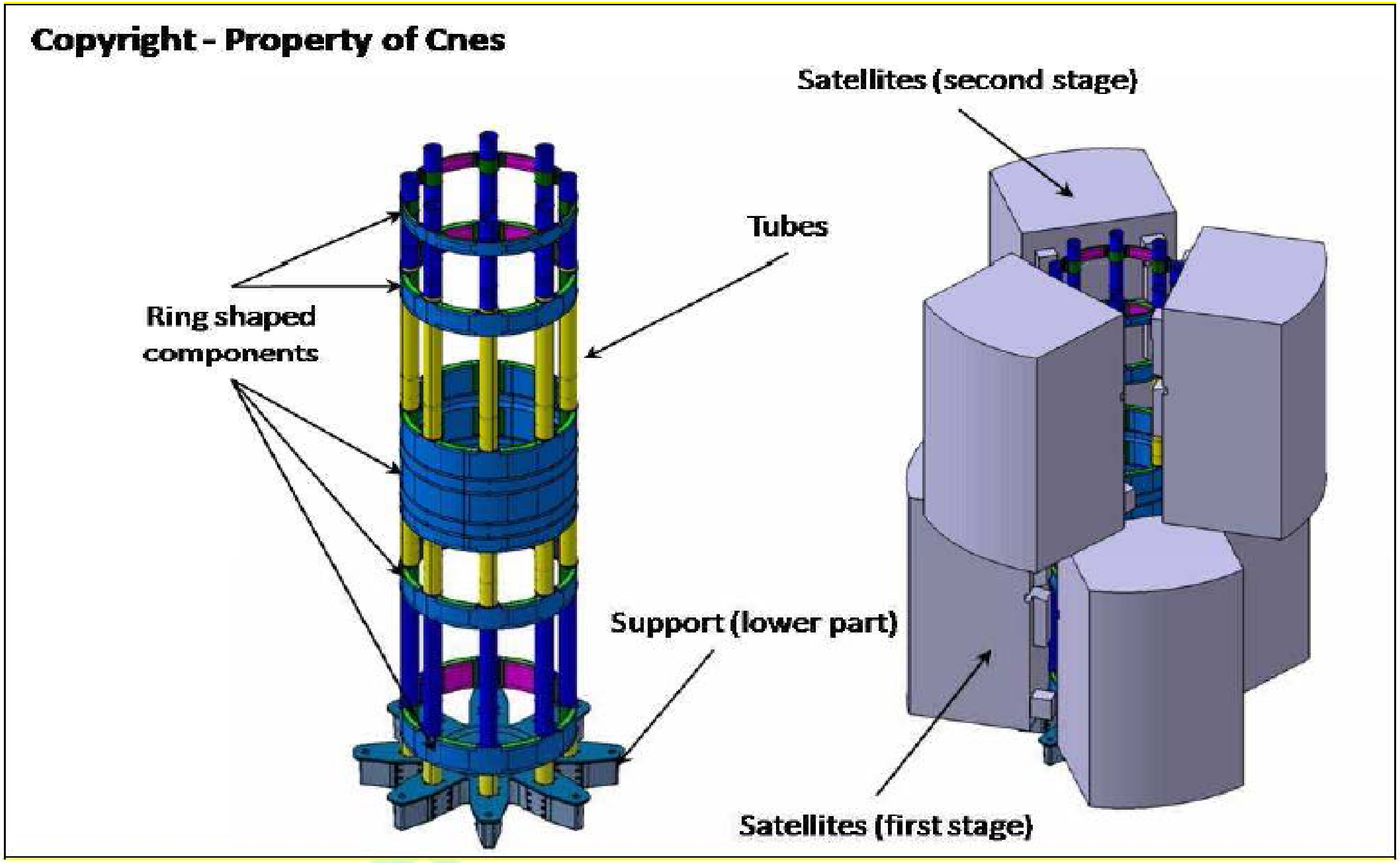
Pareto front: Acoustic cost function @TO vs global efficiency @TOC



Example 2: Design of composite structures

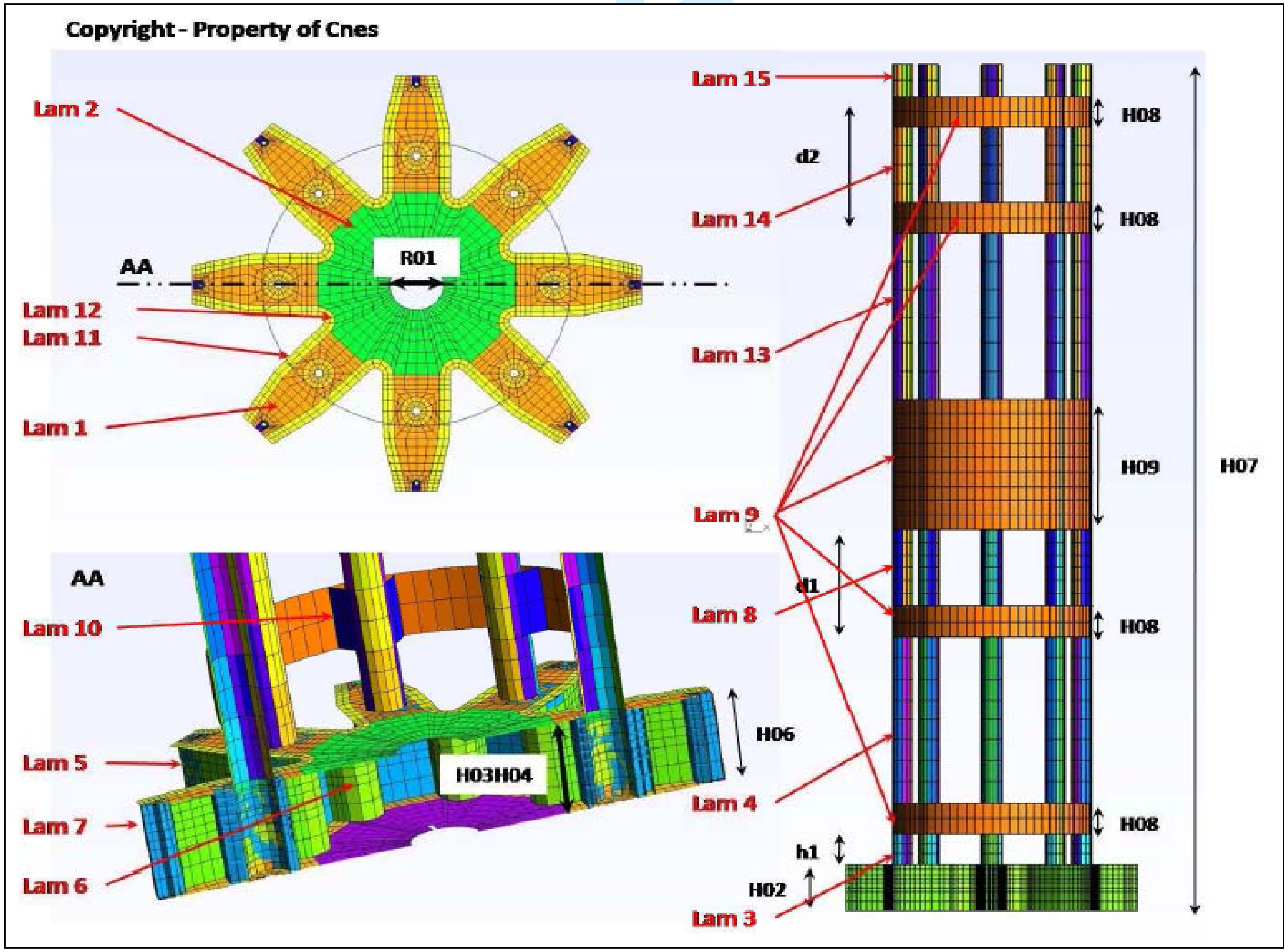


Example 2: Design and optimization of a satellites dispenser



Initial metallic design design violated constraints => composite

Design and optimization of a satellites dispenser



2 Objectives:

- minimum mass
- minimization of the frequency margin of the first lateral vibration mode

352 Constraints:

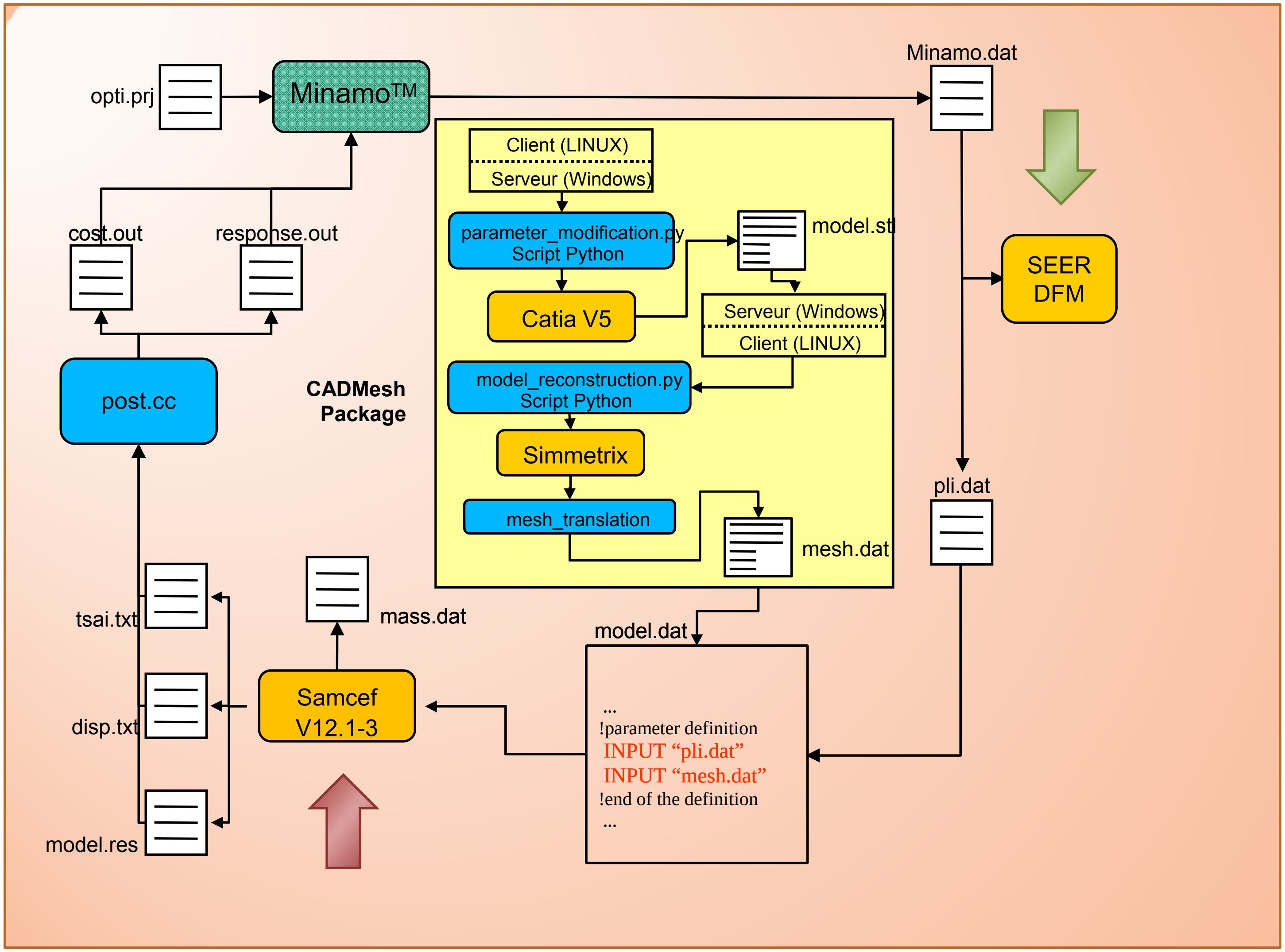
- Maximum allowed cost
- Static, dynamic
- Buckling

Design space: laminates & geometry
(25 design variables reduced to 13 after ANOVA)

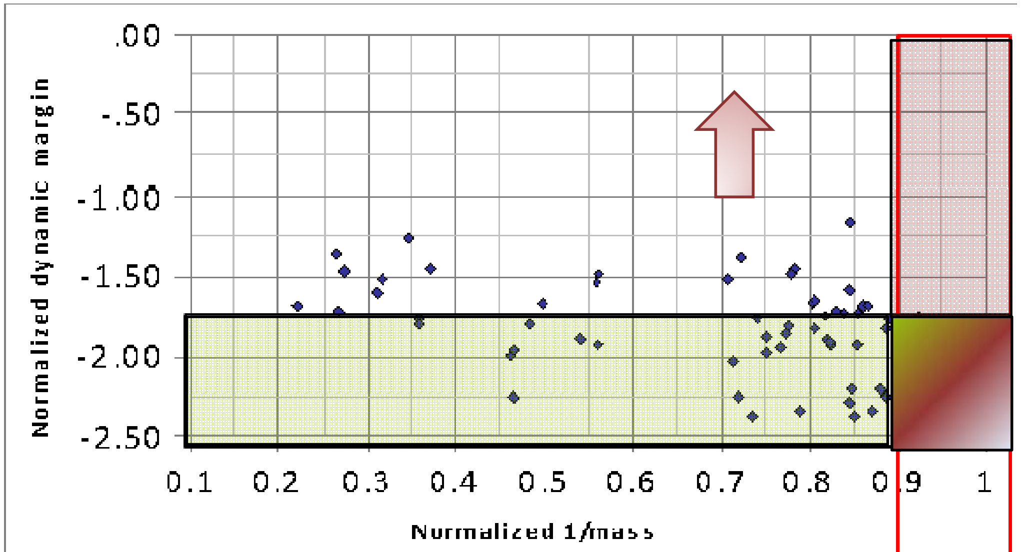
Optimization Loop Based on Samcef

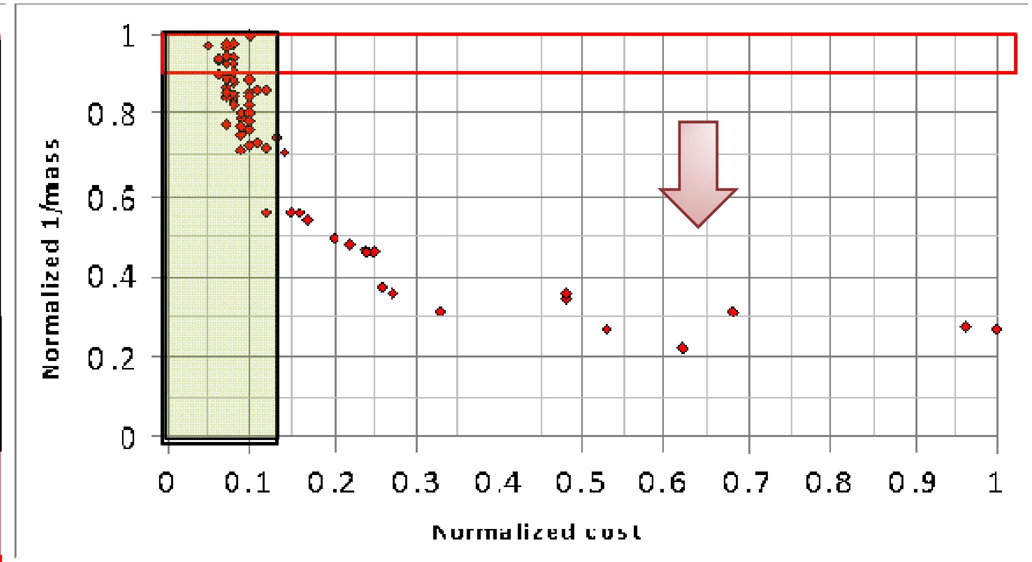
Detailed view:

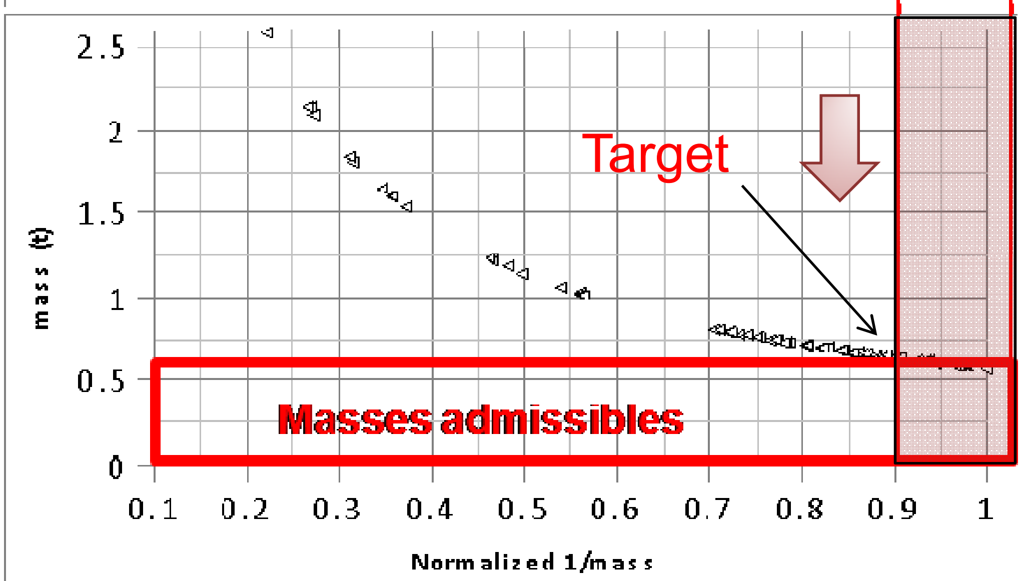
- client-server ops
- I/O operations
- meshing
- Functioning of in-house libraries



Design and optimization of a satellites dispenser



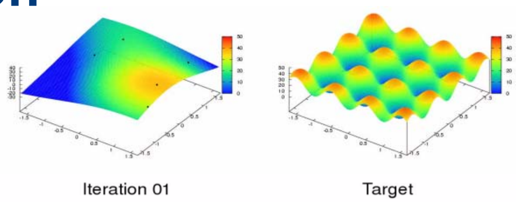




1. A slight increase of mass
2. 7% improvement of the margin on the frequency
3. Cost reduced by 12%

Ongoing developments

- **Sampling and meta-modeling**
  - Further development of auto-adaptive sampling
  - Kriging + Expected Improvement Criterion
  - Surrogate models coupling: local/global
  - RBFN (auto-)adaptive fine tuning
  - Support Vector Machines



- **Optimization - Hybridization:**
  - Memetic approaches / efficient global-local coupling
  - Exploitation of collective knowledge with multi-parent crossovers (UNDX).
  - Gradient knowledge (SPSA, FDSA, …) to be incorporated in genetic operators, e.g. gradient-based mutation.

Thank you for your attention