“Shape Optimization of Rotating Disks”

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4. High speed rotating disk optimization in pSeven
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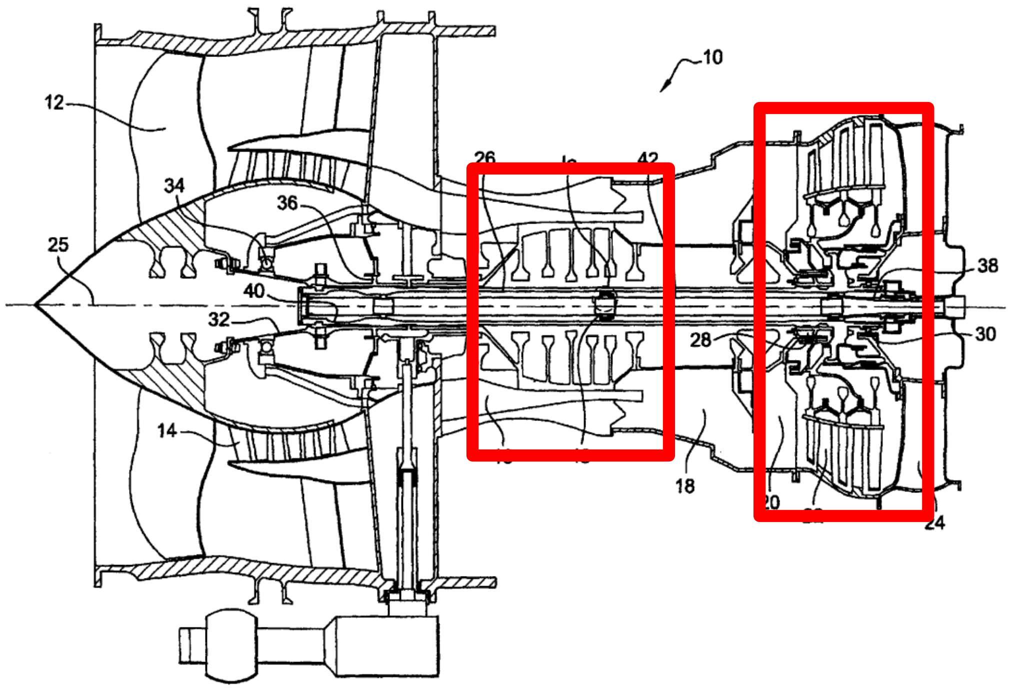
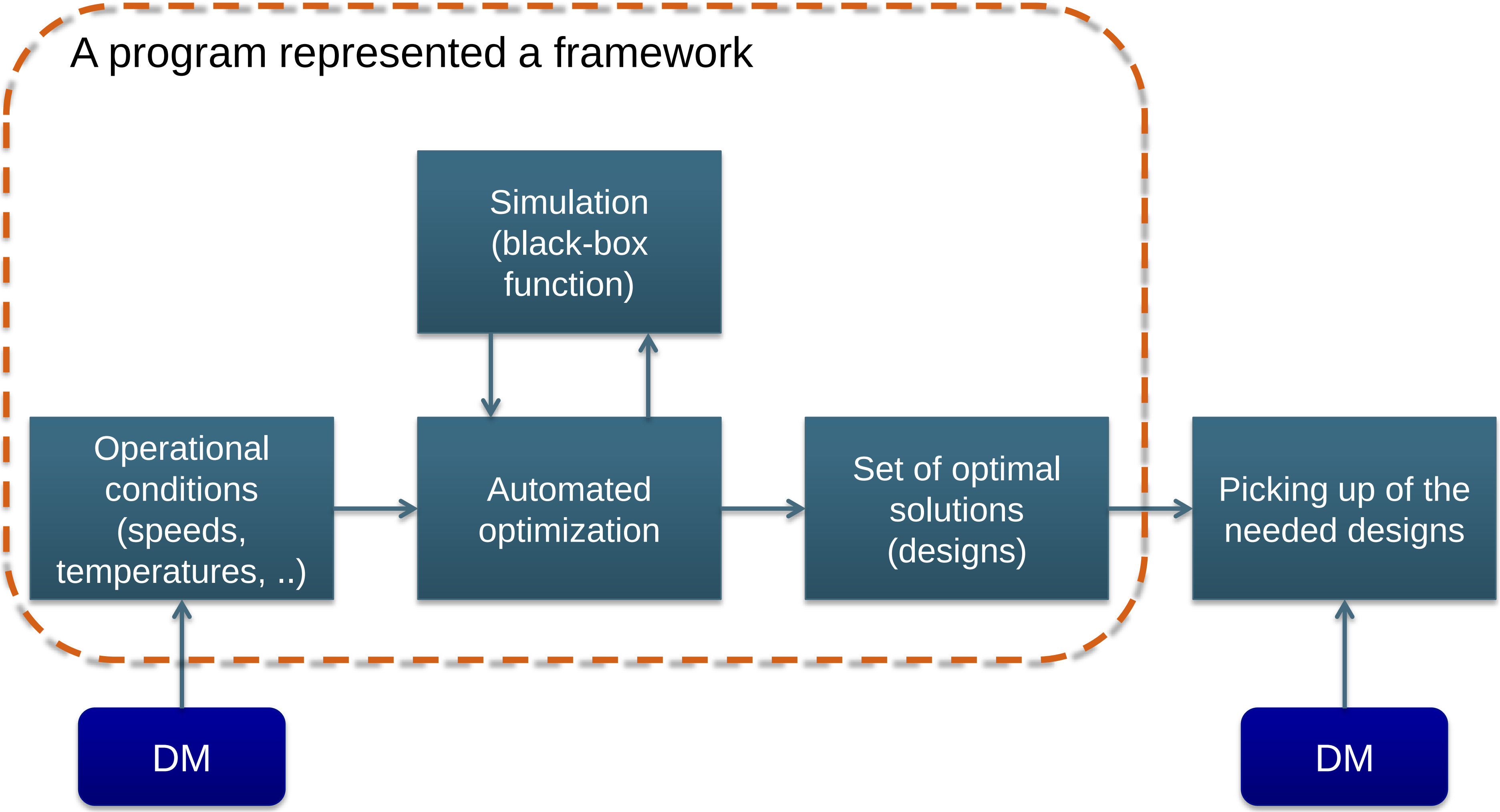
Introduction

- rotating disks with blades are wide used in different constructions
- there are ~30 rotating disk in one gas turbine engine
- on conceptual design stage an engineer needs a tool to obtain optimal shape for a future design in short time intervals



a turbojet engine

A framework for conceptual design of disks



* DM – decision maker (designer)

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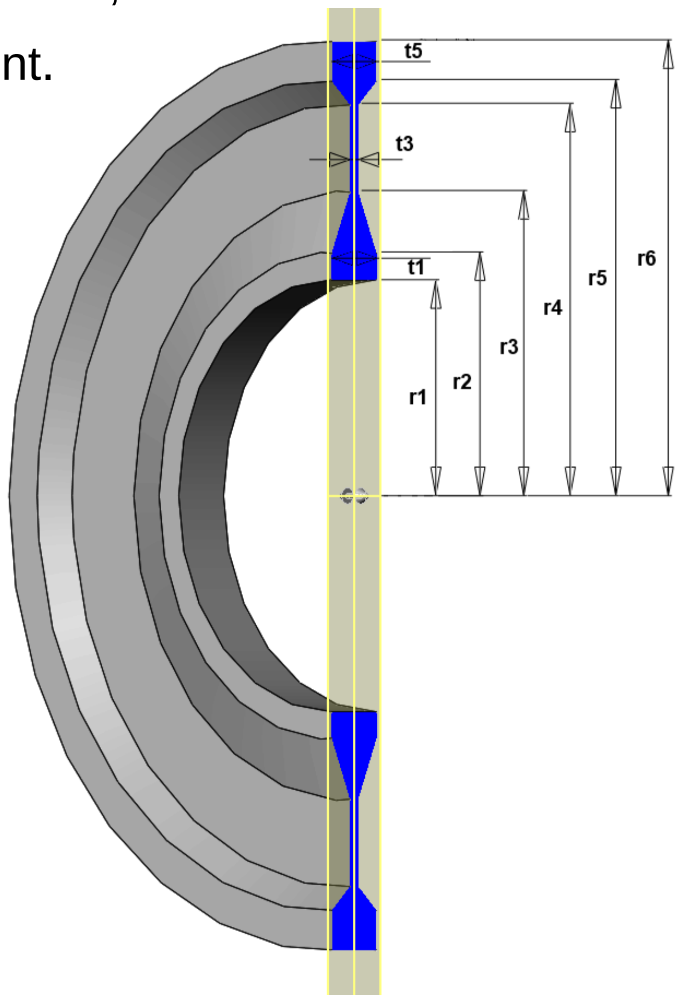
Parametrization

- One of possible parameterization schemes of disk cross section;
- it contains 9 parameters (dimensions) in millimeters;
- 3 constraints are fixed due to problem statement.

Parameter	
r1	vary
r2	vary
r3	vary
r4	vary
r5	fixed
r6	fixed
t1	vary
t3	vary
t5	fixed



Calculation scheme

Loads:

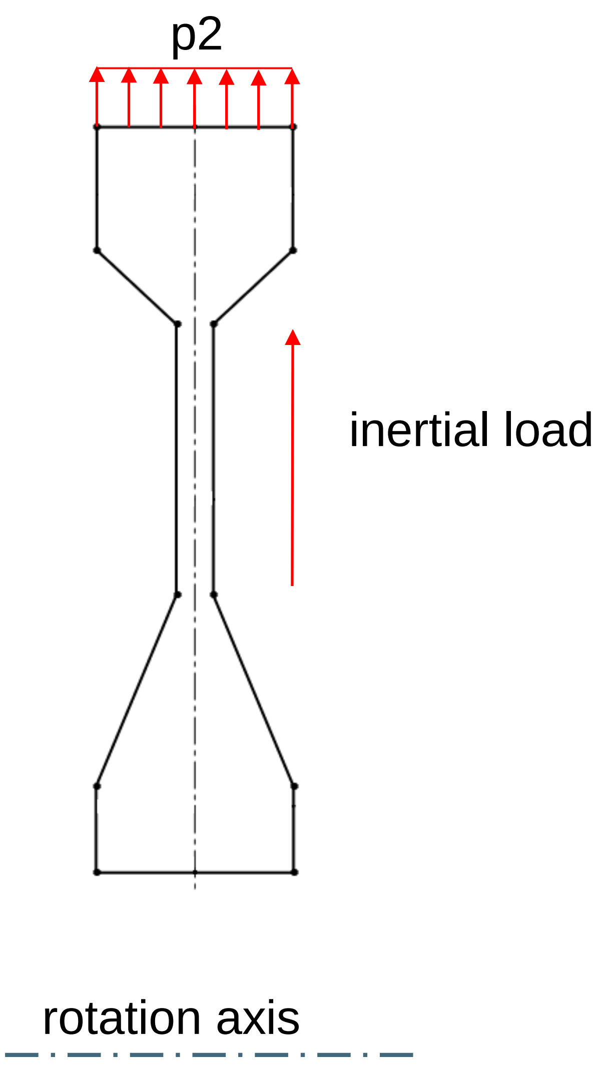
- Rotation rate (*N* rpm) ➔ inertial load;
- Uniform pressure load from blades (*p2*).

Physics:

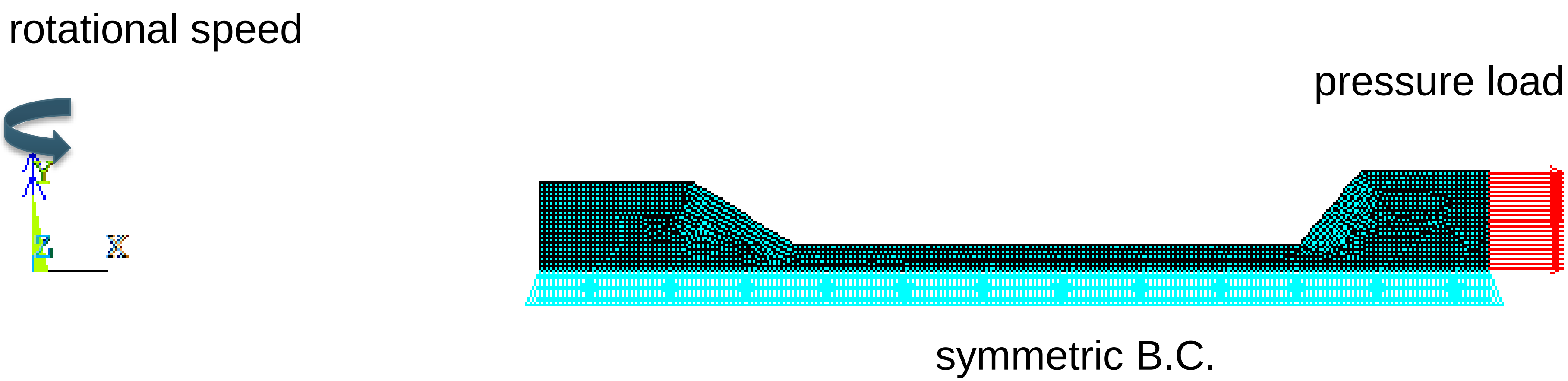
- Linear material model (*E, ρ, μ*)

Assumptions:

- Plane stress;
- Axisymmetric scheme;
- Small strains and displacements;
- The interaction with other rotating parts are neglected.

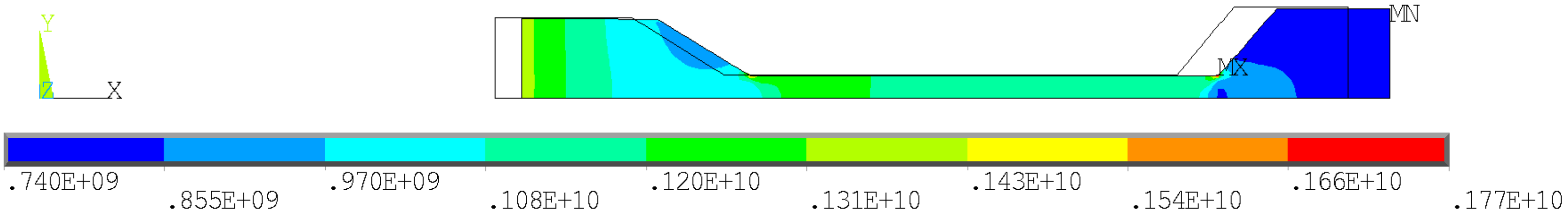


Ansys: Boundary Conditions

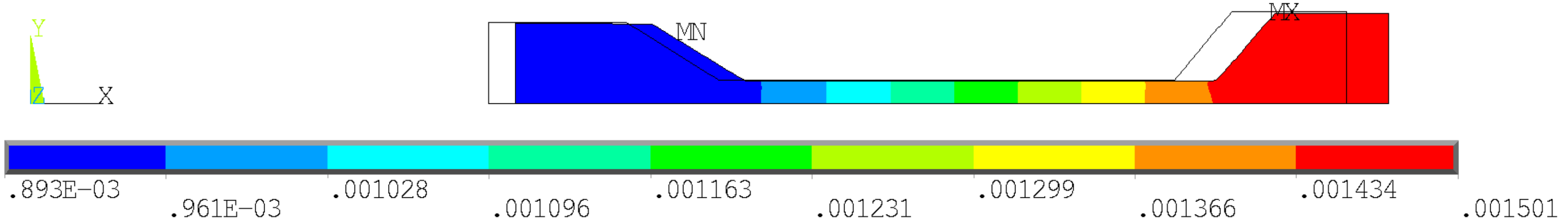


Ansys: Postprocessing

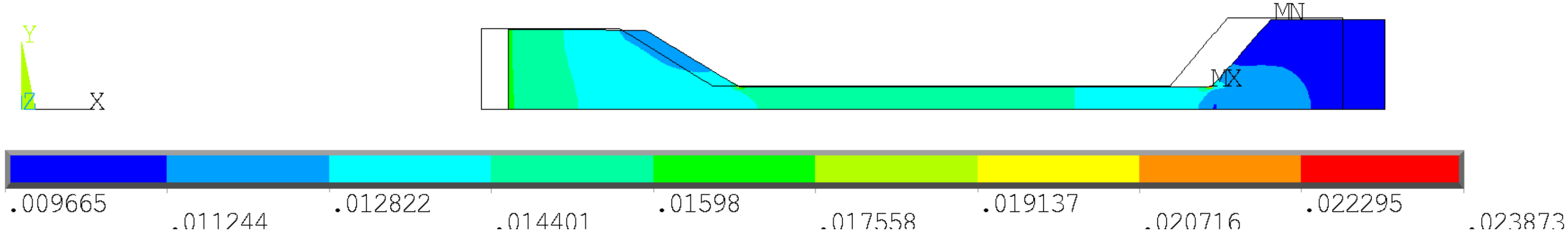
Equivalent stress, Pa



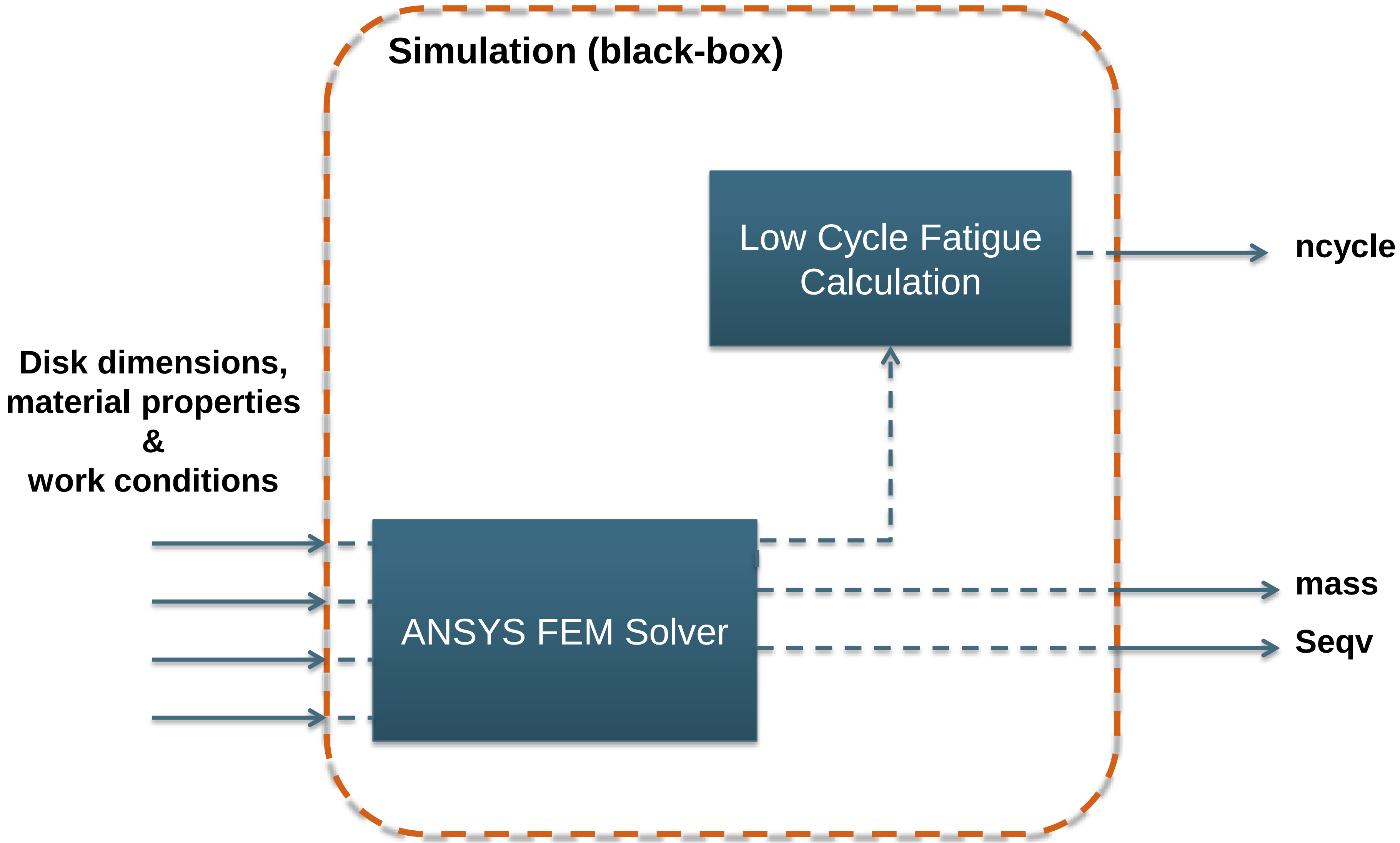
Displacements, mm



Strain intensity



Simulation responses



Low Cycle Fatigue: Manson Approximation

- Manson proposed a simplified formula known as the method of universal slopes

$$De = 3.5 \frac{S_u}{E} N^{-0.12} + D^{0.6} N^{-0.6},$$

where:

De - the amplitude of altering strains,

S_u - the ultimate tensile stress,

E - elastic modulus,

D - ductility.

Ref.: *Manson SS. Behavior of materials under conditions of thermal stress. Technical Report NACA-TR-1170, National Advisory Committee for Aeronautics; 1954*

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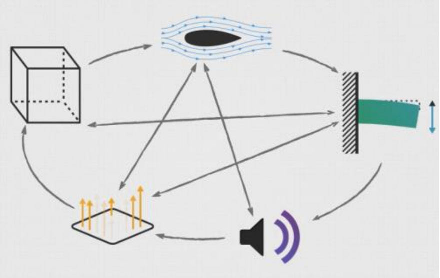
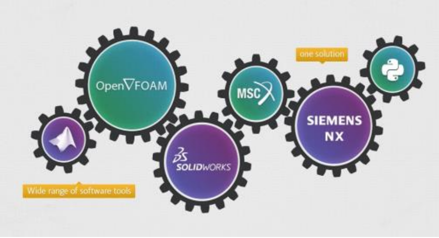
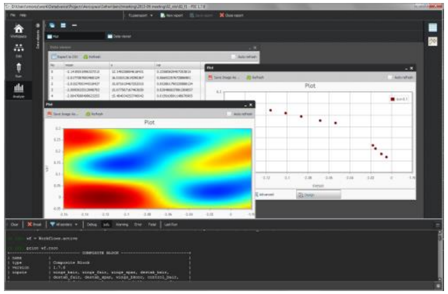
pSeven: Main Features



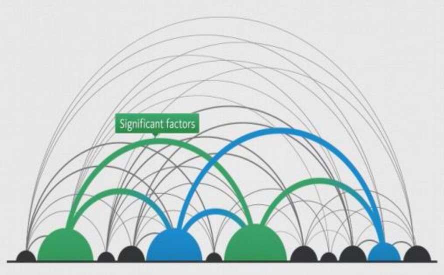
Visual process integration



Workflow execution



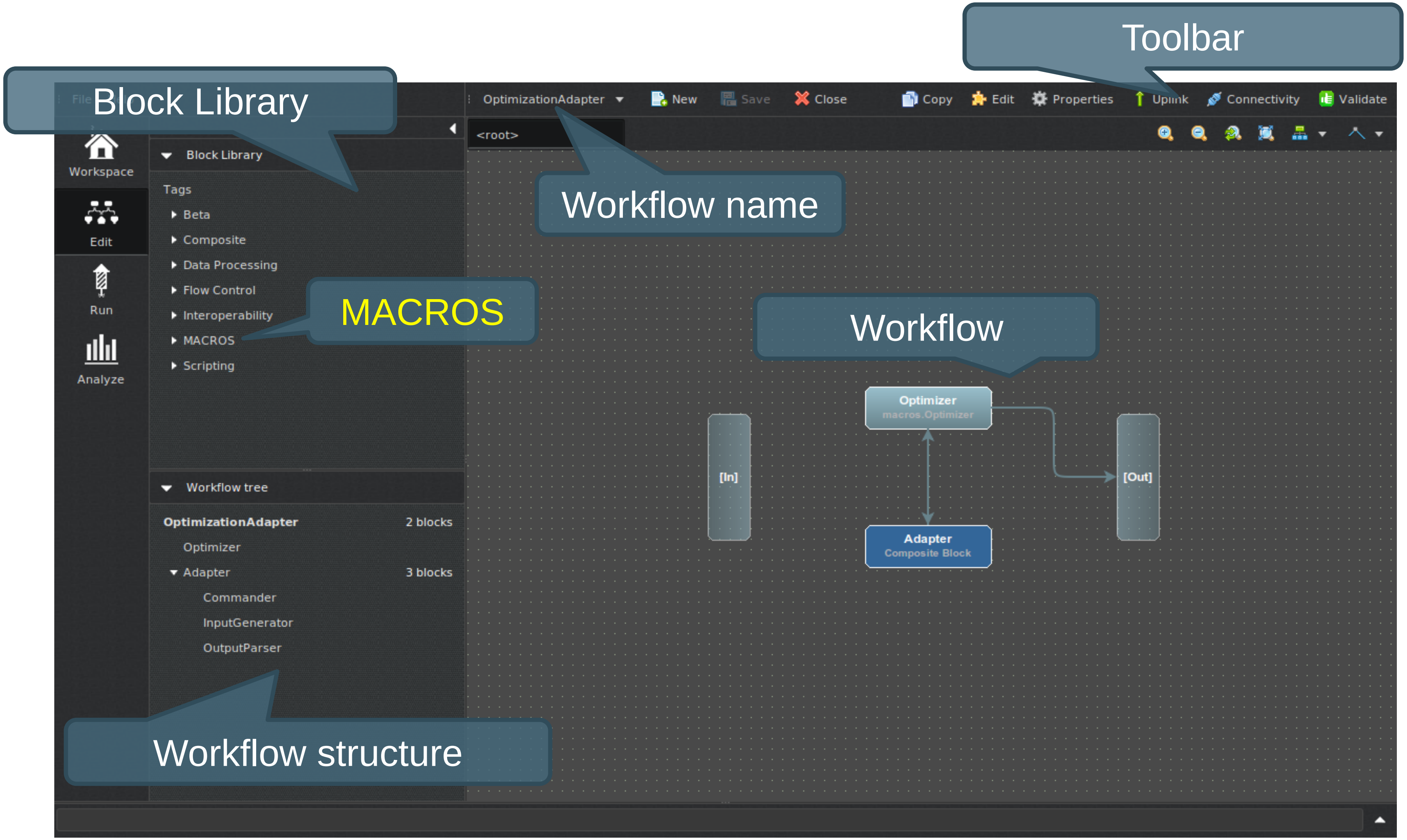
Results visualization and analysis



Data mining and optimization

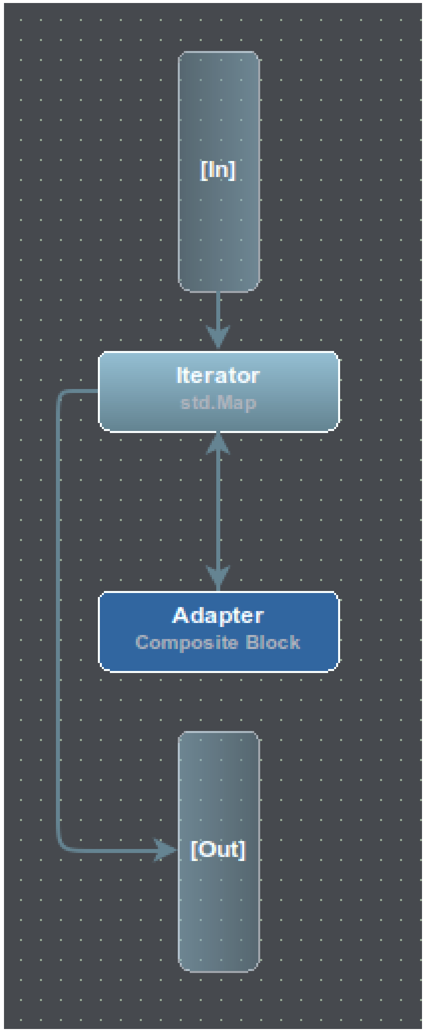
Key advantage

Graphical User Interface



Workflow

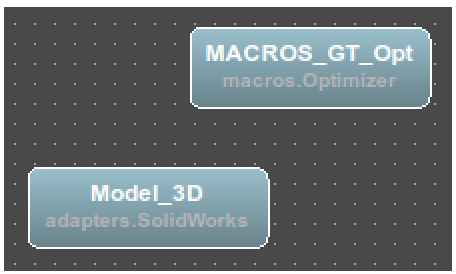
- Workflow – a representation of problem solving process, a combination of blocks and links
- Block – an independent functional component Examples:
  - *std.Optimizer* – optimization problem solver
  - *std.PythonScript* – Python integration block
- Link – a data channel connecting blocks, links *implicitly* specify block execution order
- Grouping – ability to assemble composite blocks containing other blocks and links (sub-workflow)



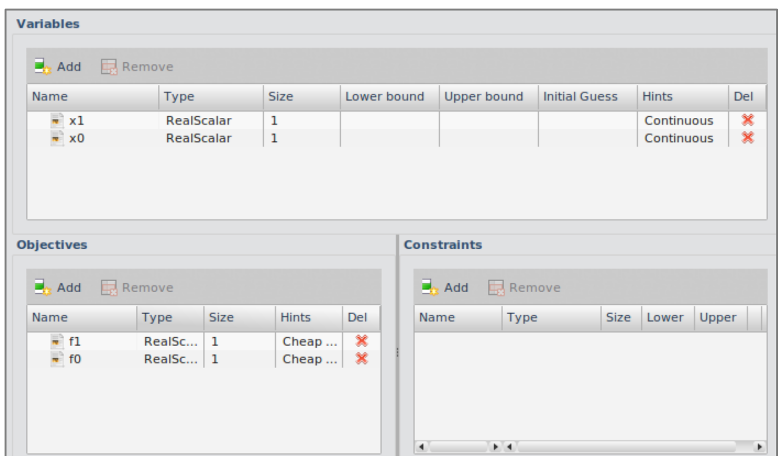
Creating Workflows

Principal steps:

- Add blocks to the workflow
- Configure blocks
- Connect ports with links



✔	MACROS_GT_Opt		Model_3D
☑	x0	→	x0
☑	x1	→	x1
☑	f0	←	f0
☑	f1	←	f1



Variables

Add Remove

Name	Type	Size	Lower bound	Upper bound	Initial Guess	Hints	Del
x1	RealScalar	1				Continuous	✖
x0	RealScalar	1				Continuous	✖

Objectives

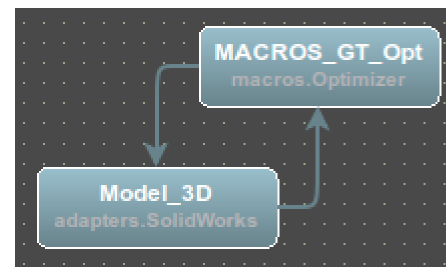
Add Remove

Name	Type	Size	Hints	Del
f1	RealSc...	1	Cheap ...	✖
f0	RealSc...	1	Cheap ...	✖

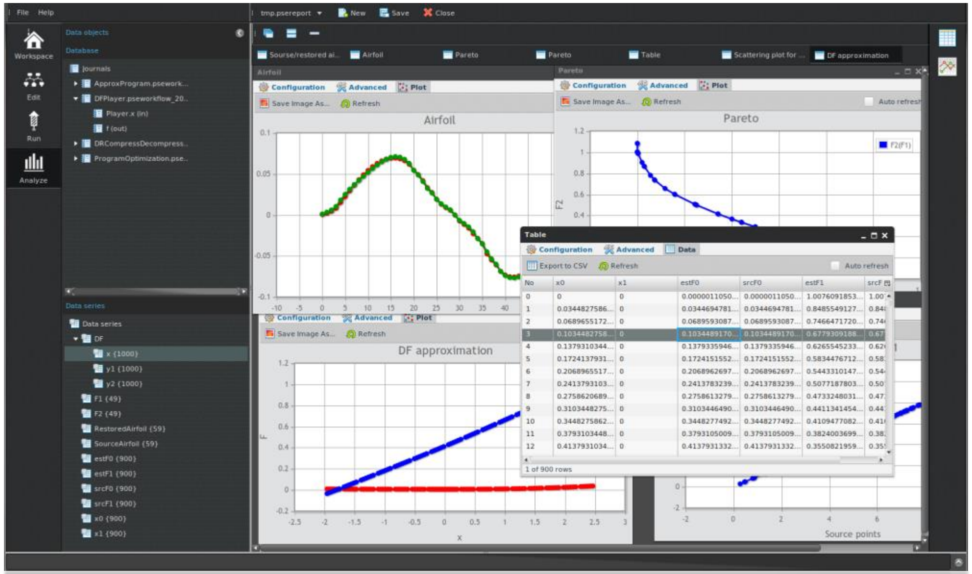
Constraints

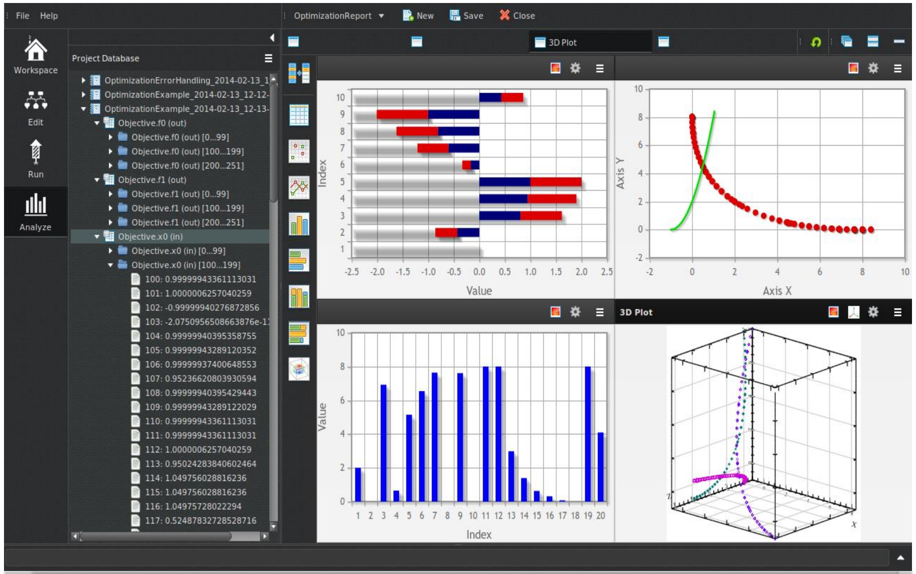
Add Remove

Name	Type	Size	Lower	Upper



Results Visualization and Analysis





Rich post-processing and data analysis tools

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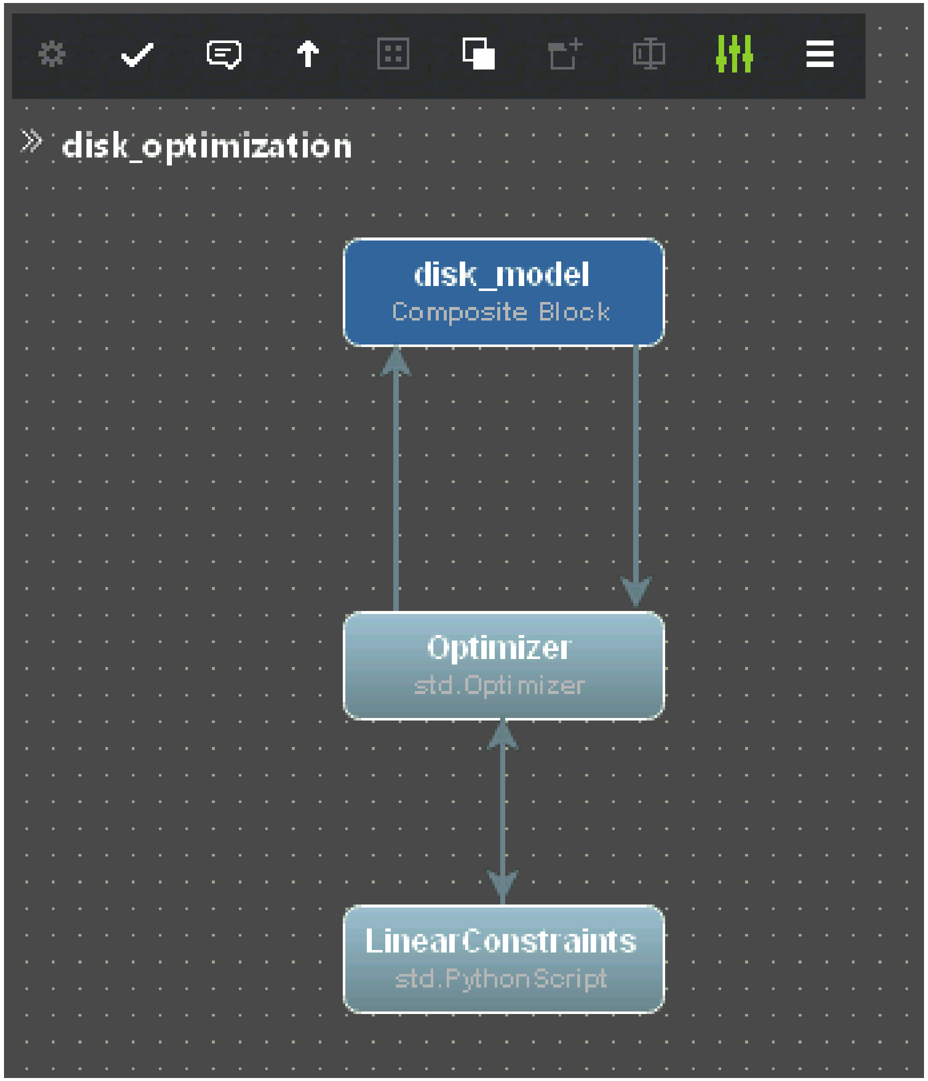
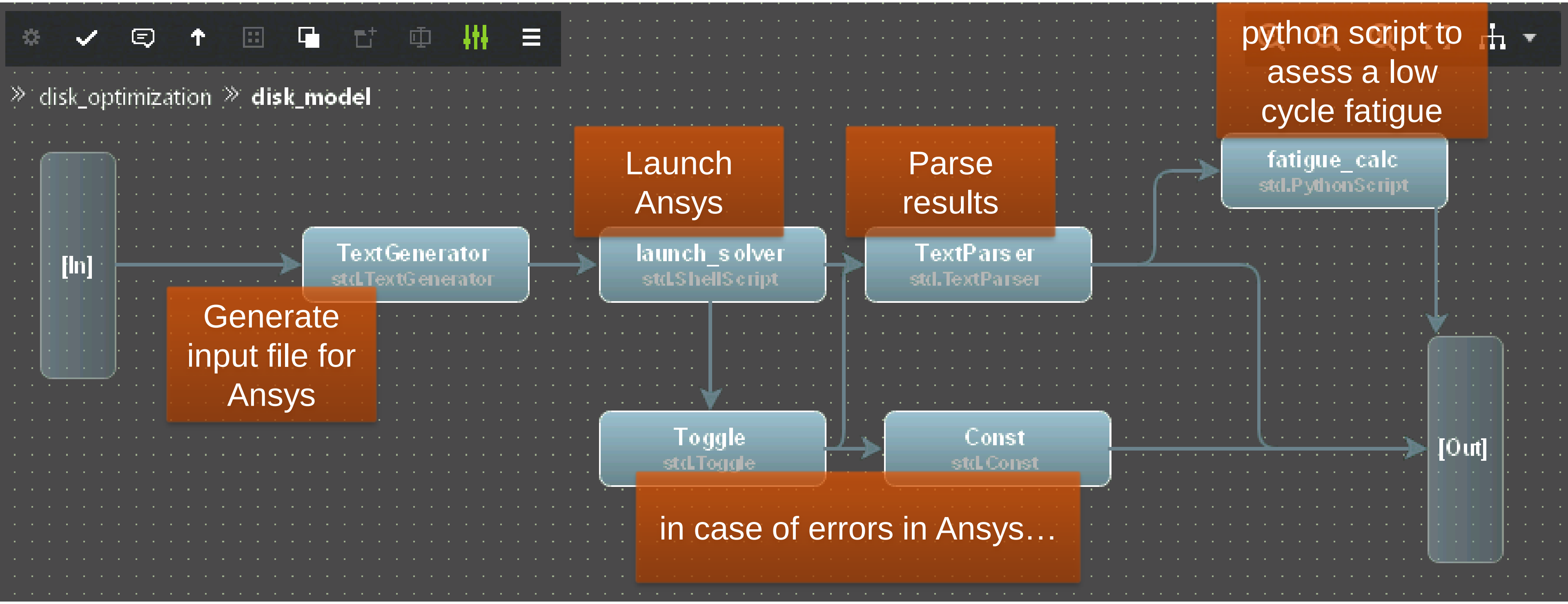
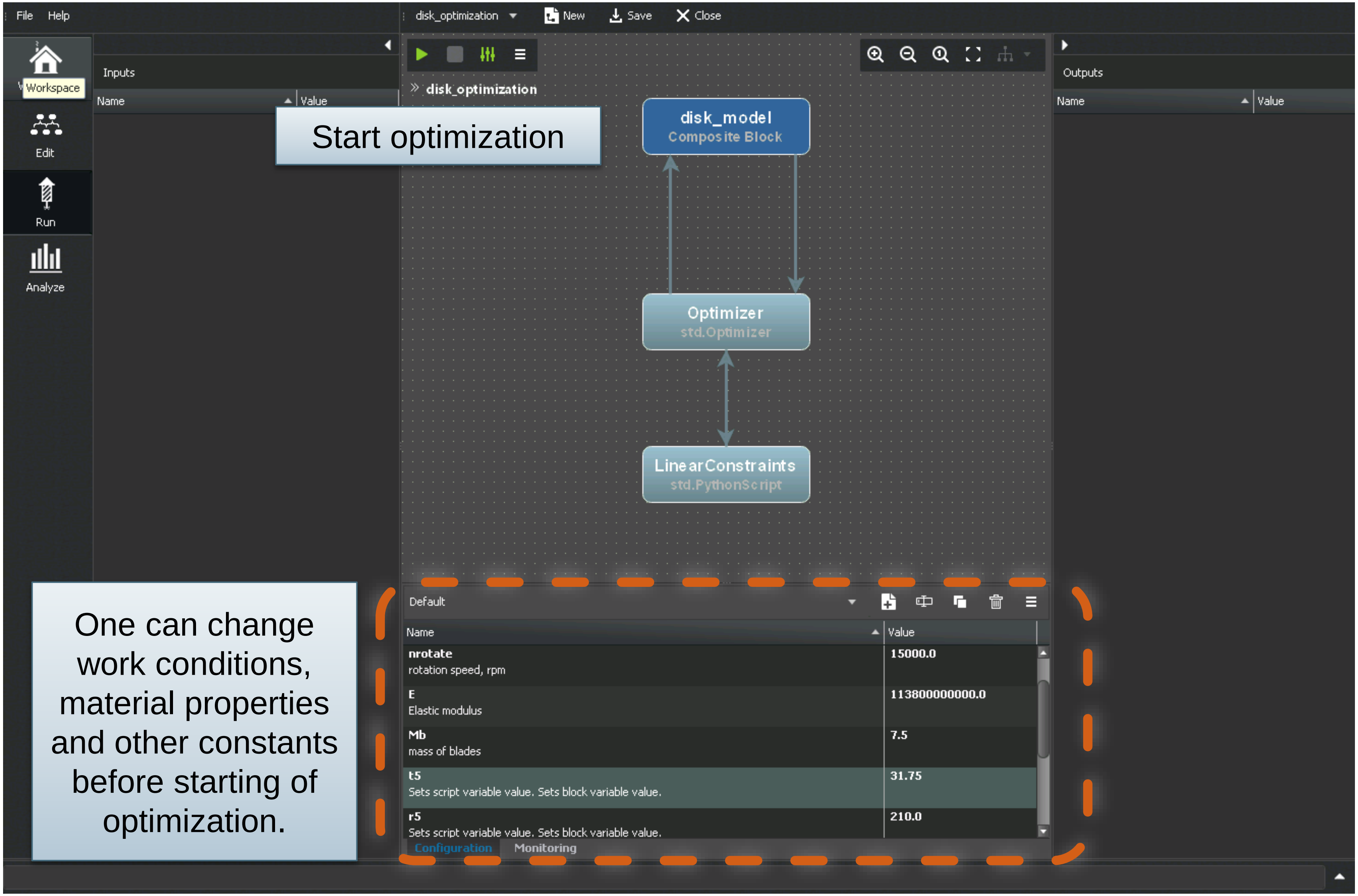
Workflow for HSRD optimization: top level



Workflow for HSRD optimization: disk_model



Workflow Configurations



Start optimization

One can change work conditions, material properties and other constants before starting of optimization.

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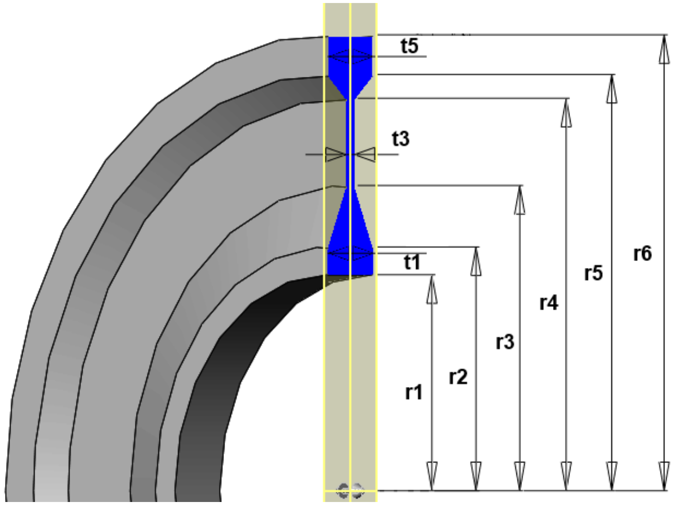
Optimization Problem Statement

Parameters:

Parameter	MIN	MAX
r1, [mm]		
r2, [mm]		
r3, [mm]		
r4, [mm]		
t1, [mm]		
t3, [mm]		



Constraints:

Constraint	description	type
r2 - r1 > 1	geometry consistency	linear
r3 - r2 > 1		linear
r4 - r3 > 1		linear
r5 - r4 > 1		linear
t1 - t3 > 0	preferred thicknesses	linear
Seqv < 1000 [Mpa]	static strength requirement	general

Optimization Problem Statement

Objectives :

Objective	description	type
mass	mass of the disk	general
ncycle	number of cycle until failure	general

Optimization Method:

- **Descend-diffusion multi-objective optimization method** is incorporated in pSeven;
- This method allows to find exact predefined number of solutions on Pareto-front;
- Most calculations are laying near the Pareto-front.

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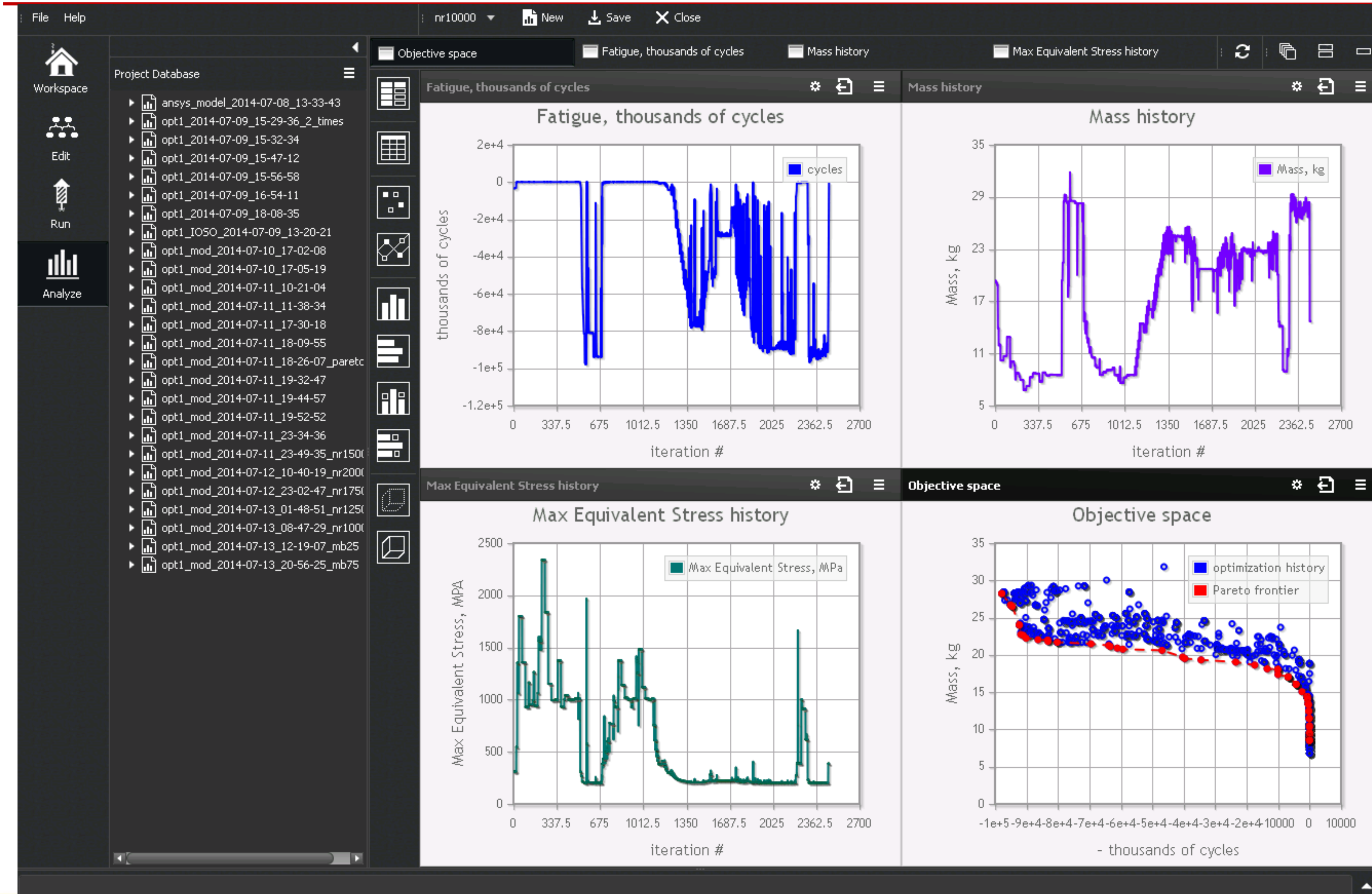
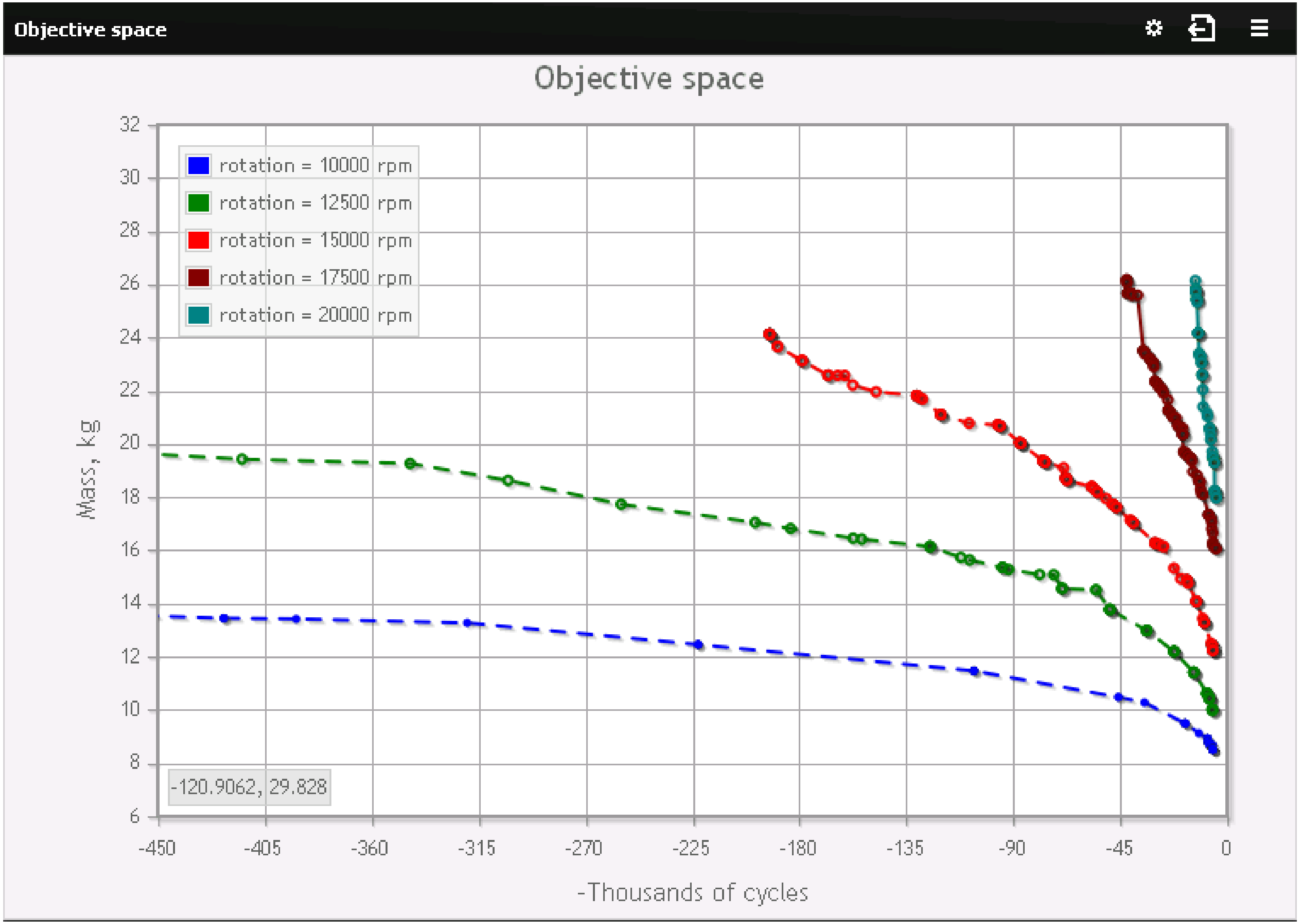
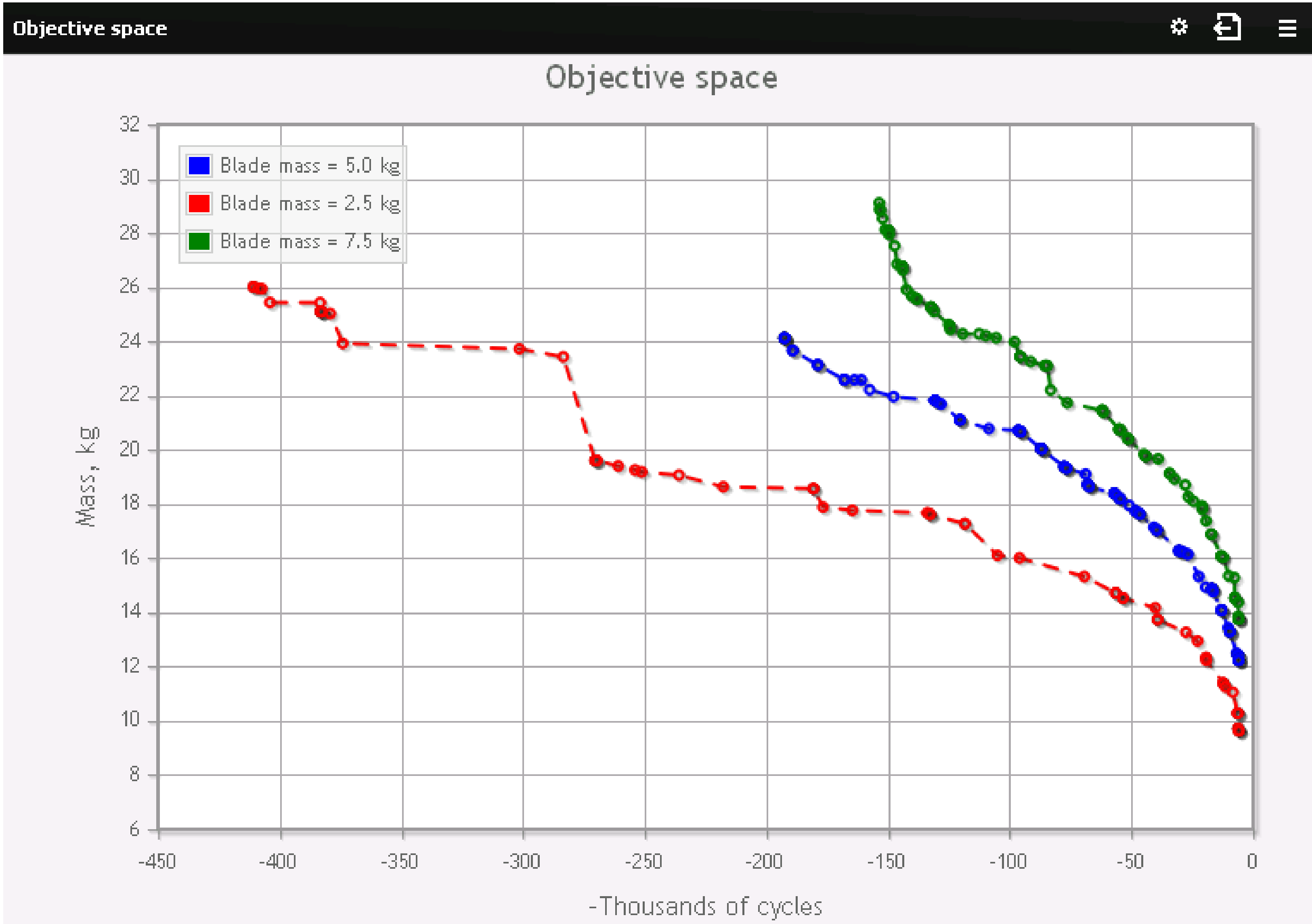
Single optimization



Different rotation speeds investigation



Different blade masses investigation



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Conclusion

- pSeven can be used to set up a framework for design analysis and optimization for some structural objects;
- The descend-diffusion optimization method shows good convergence speed and can be used for engineering purpose;
- The obtained results can be used in conceptual design stage of gas turbine engine designing.

Future improvements

- Improving in a simulation:
  - use real-flight mission conditions (regimes);
  - more comprehensive model for low cycle fatigue.

- Improving in an optimization:
  - calculations parallelization;
  - try different parameterization schemes.

Thanks for your attention!

Visit our website

www.datadvance.net

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