Kaplan turbine rotor optimization using CAESES

Faculty of Civil Engineering
CTU in Prague

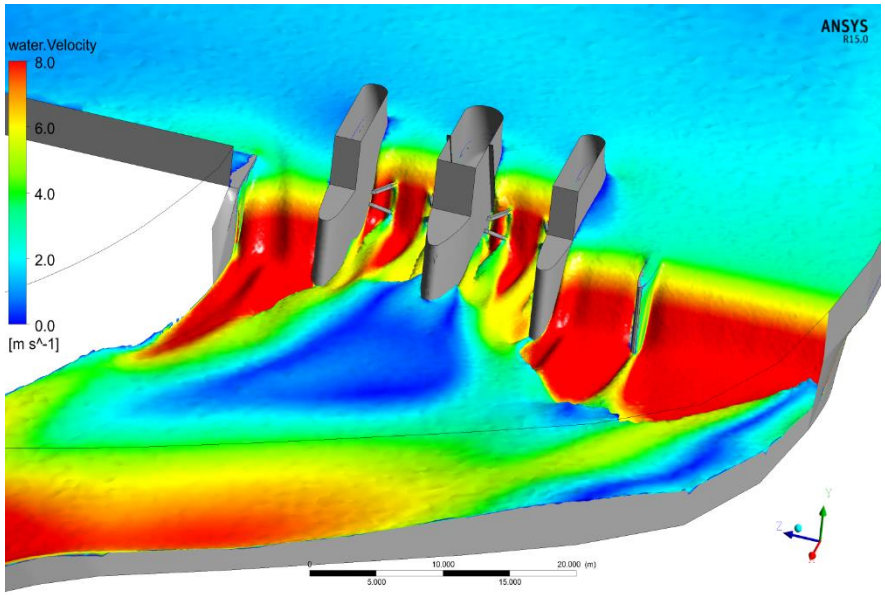
Faculty of Mechanical Engineering
UJEP in Ústí nad Labem

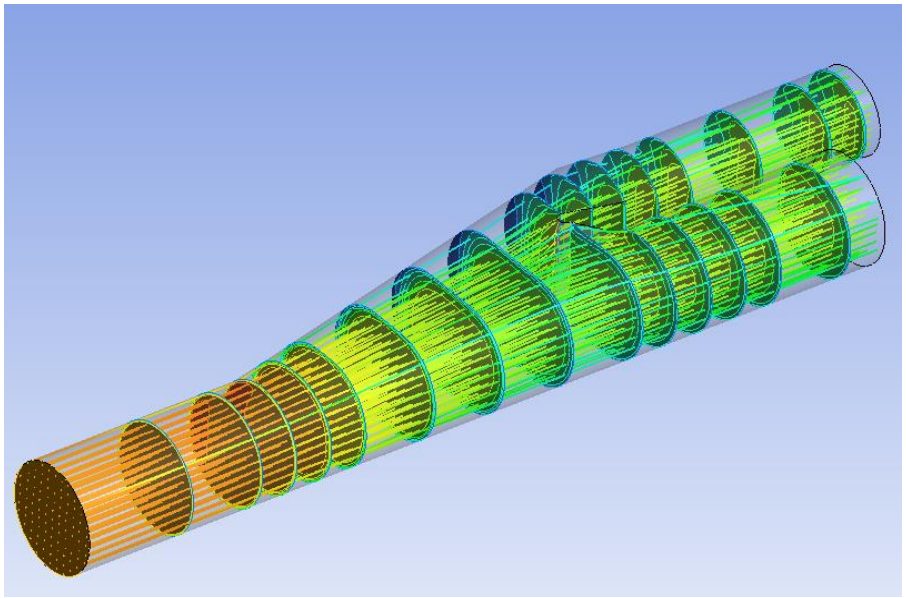
Department of Hydraulic Structures

Ing. Jiří Souček
Ing. Eva Bílková
Dr. Ing. Petr Nowak

Institute of Machines and Power Engineering

Ing. Martin Kantor, PhD.





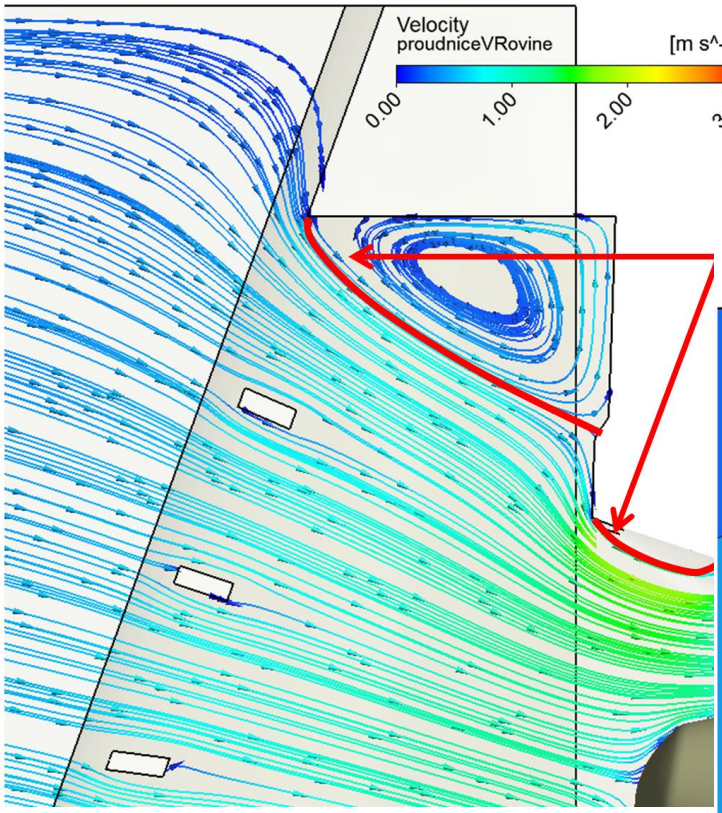
Acknowledgment
This works was supported by TACR, project no. TH04010140.

CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

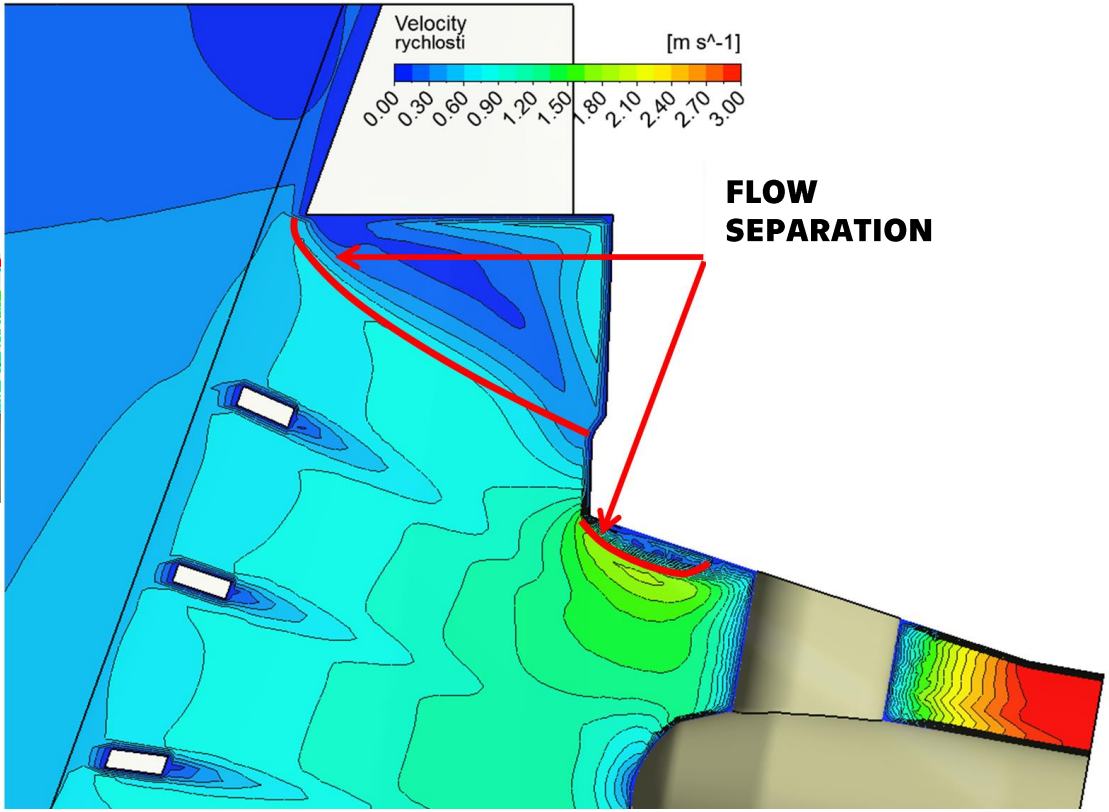
UJEP

FLUID FLOW ANALYSIS

- large hydraulic structures (dams, weirs, gates)
- small hydro intakes
- turbo



FLOW SEPARATION



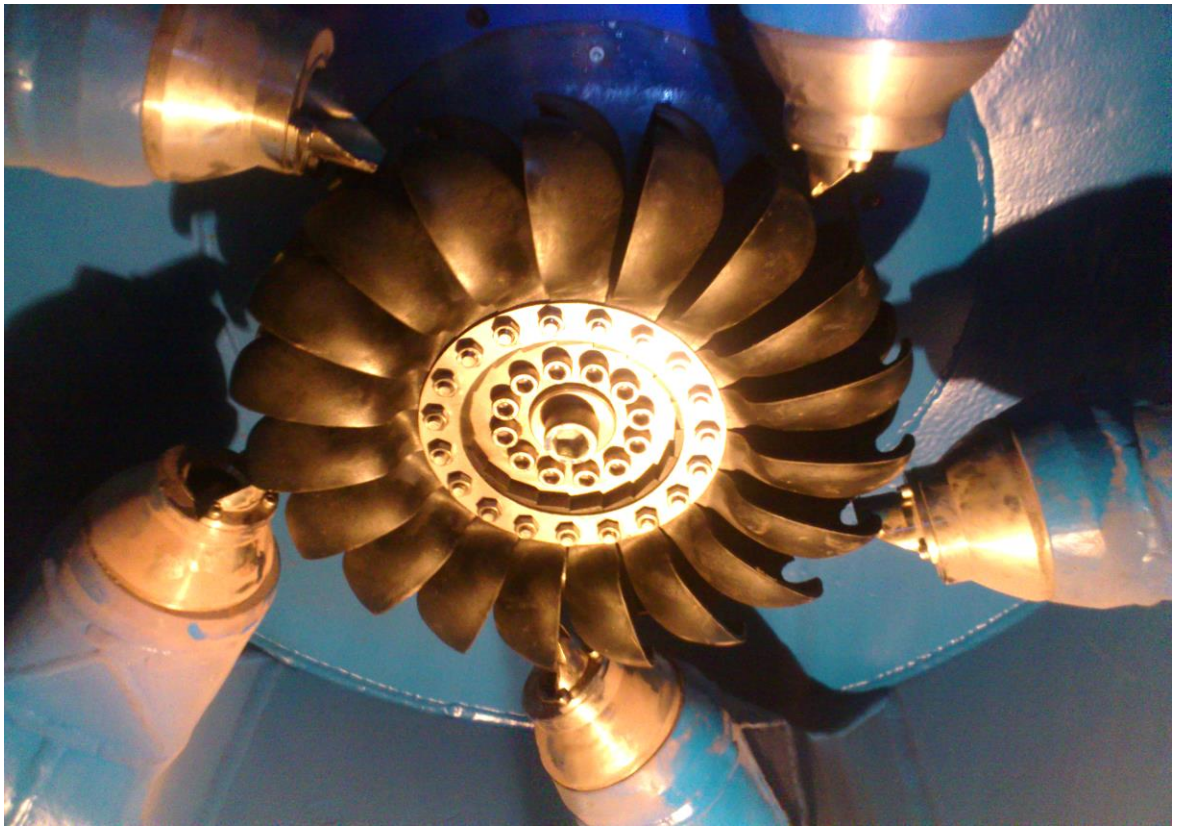
FLOW SEPARATION

CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

UJEP

MICRO-HYDRO DESIGN

- rapid prototyping (3D printing, pressure mold injection)
- innovative design (variable speed)



CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

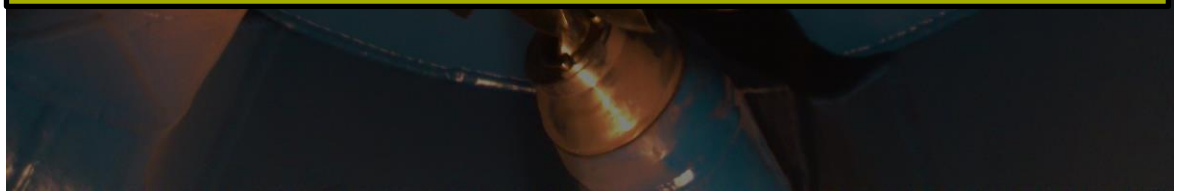
UJEP

MICRO-HYDRO DESIGN

- rapid prototyping (3D printing, pressure mold injection)
- innovative design (variable speed)

NEW DESIGN CHALLENGES

optimization using CAESES



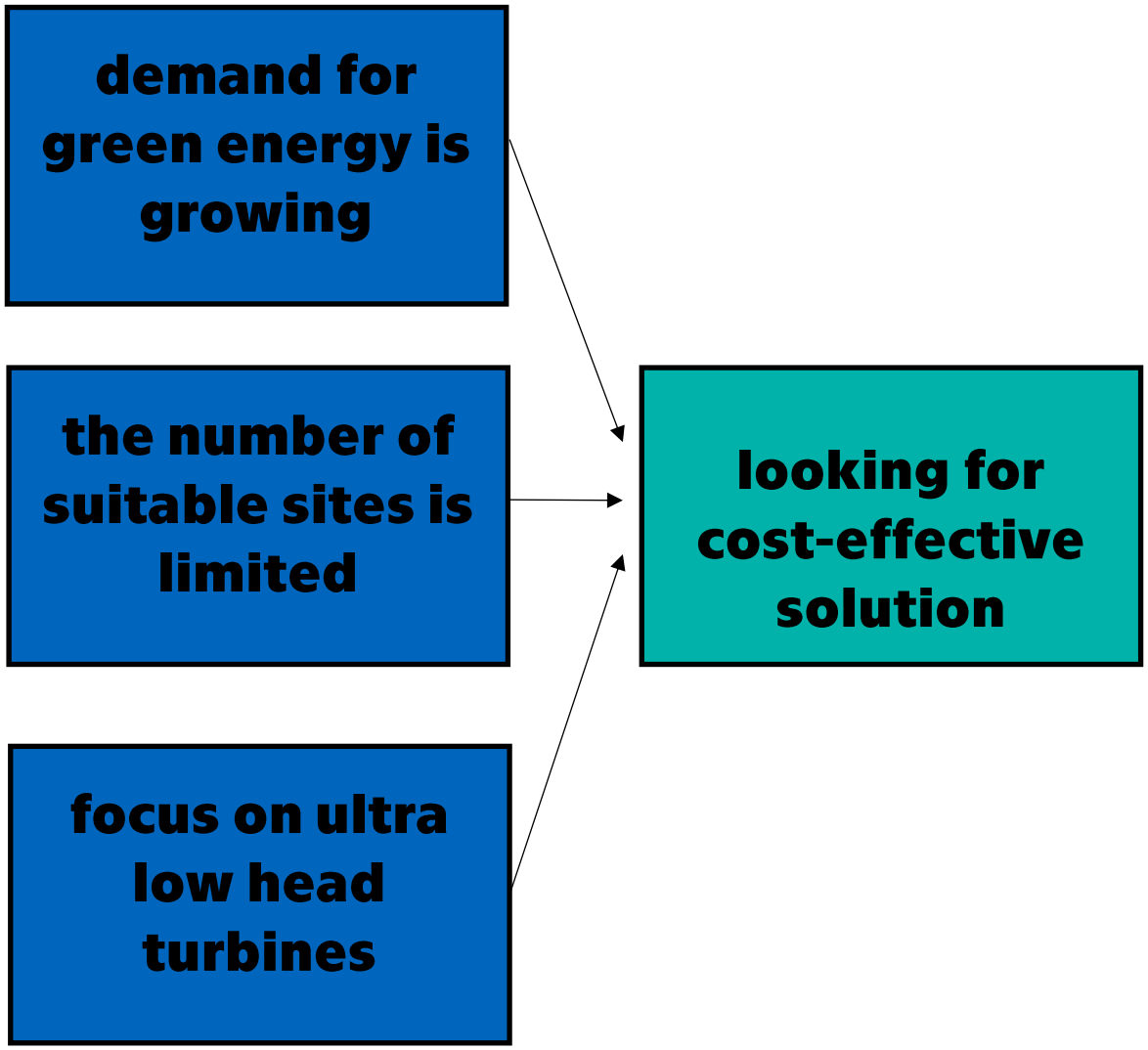
CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

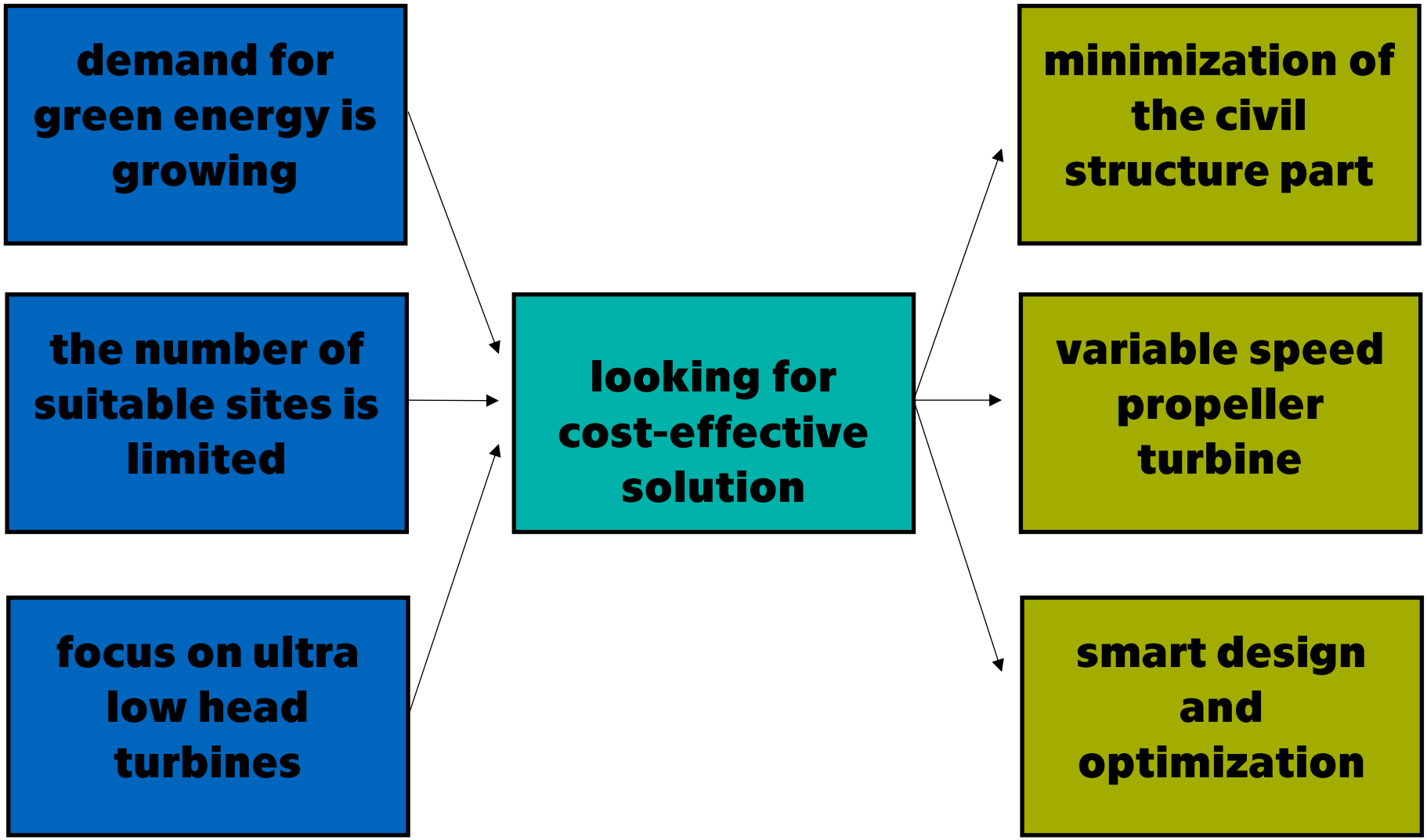
UJEP

demand for green energy is growing

the number of suitable sites is limited

focus on ultra low head turbines


demand for green energy is growing
the number of suitable sites is limited
focus on ultra low head turbines
looking for cost-effective solution

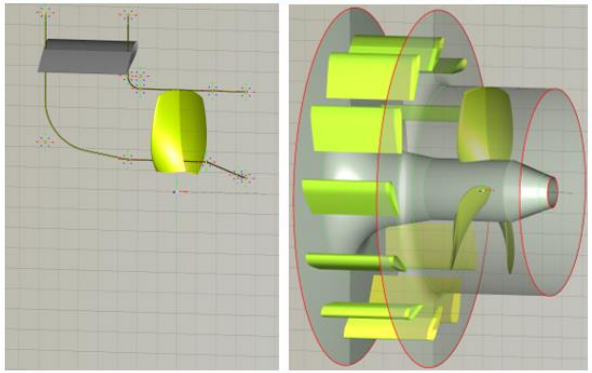

demand for green energy is growing
the number of suitable sites is limited
focus on ultra low head turbines
looking for cost-effective solution
minimization of the civil structure part
variable speed propeller turbine
smart design and optimization

CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

UJEP

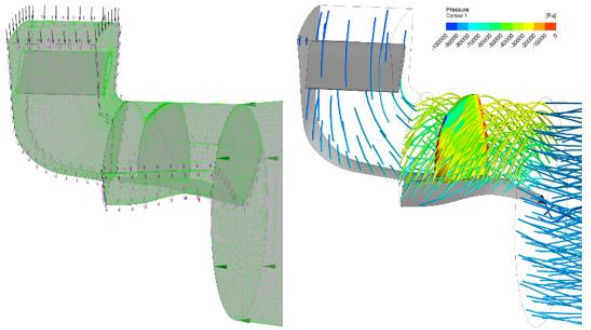
CAESES

PARAMETRIC MODELS OF GEOMETRY



ANSYS
CFX

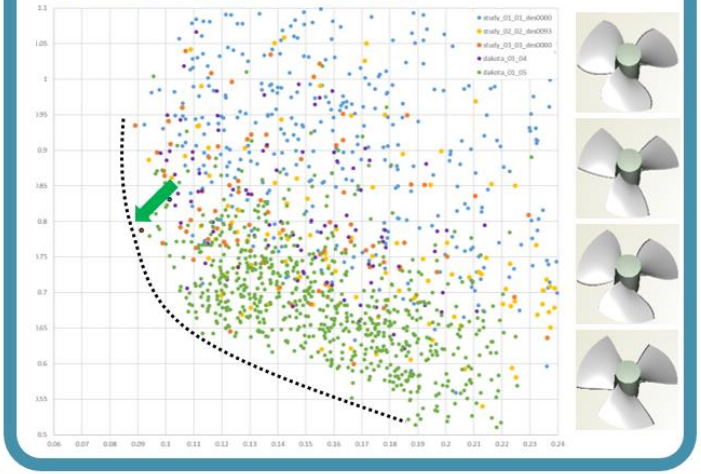
FLUID FLOW ANALYSIS



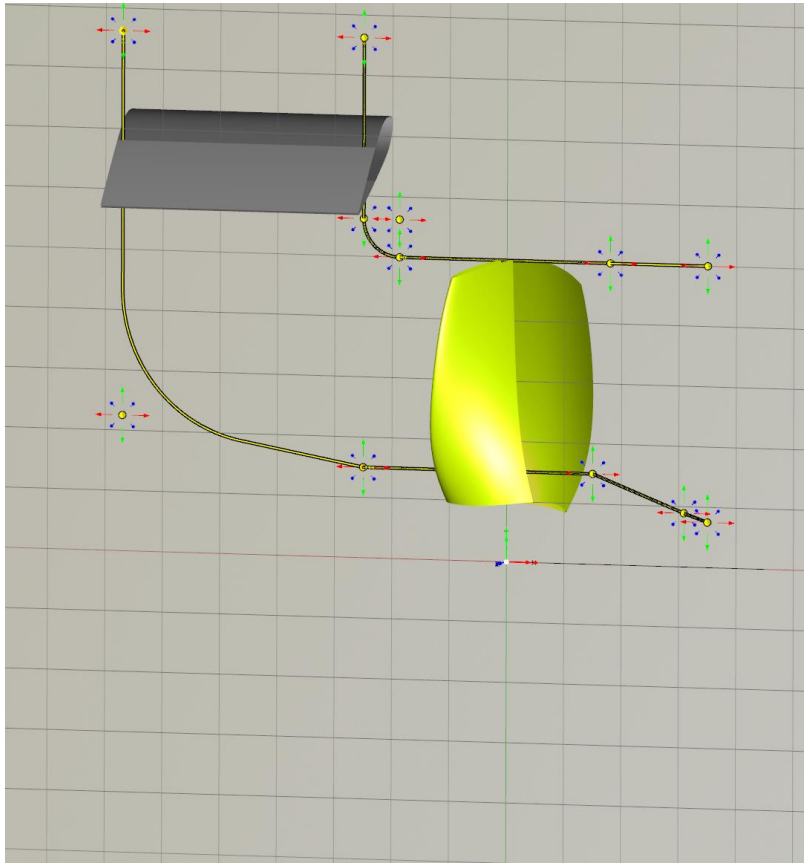
SW CONNECTION

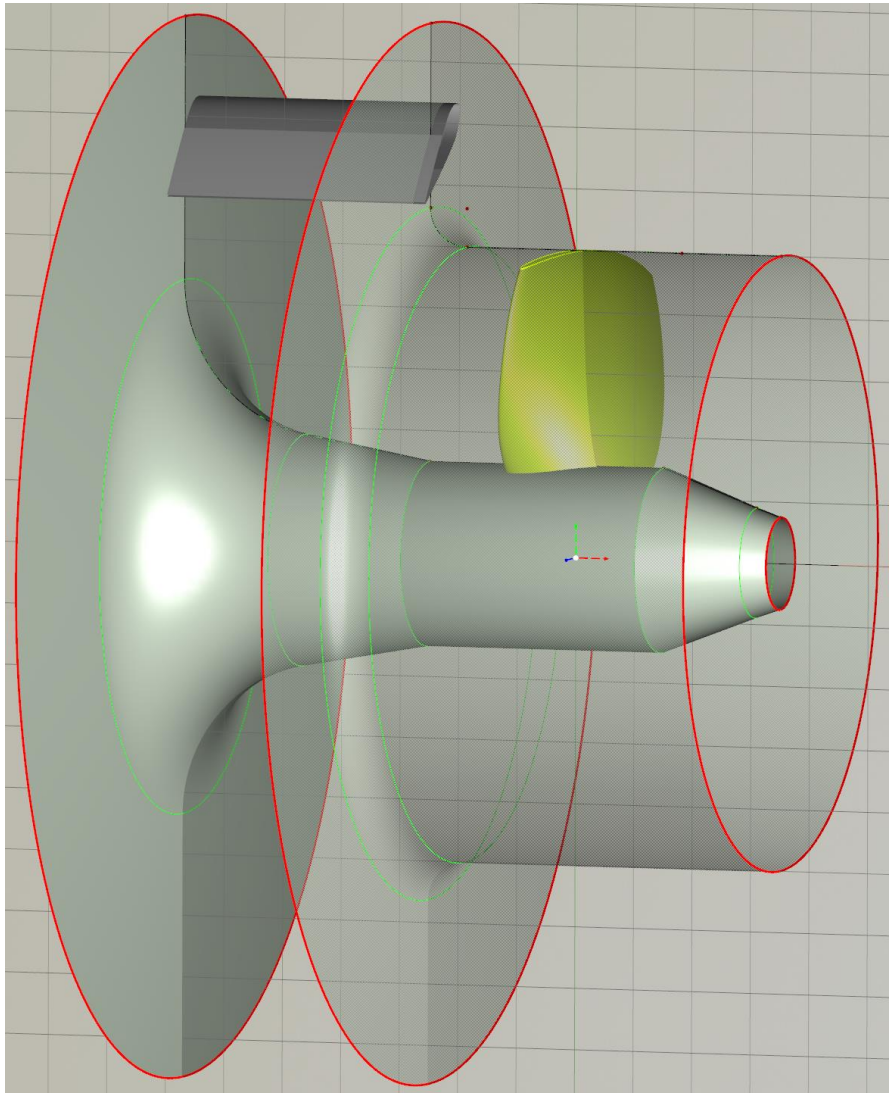
DAKOTA
Explore and predict with confidence.

OPTIMIZATION - MOGA



SENSITIVE ANALYSIS



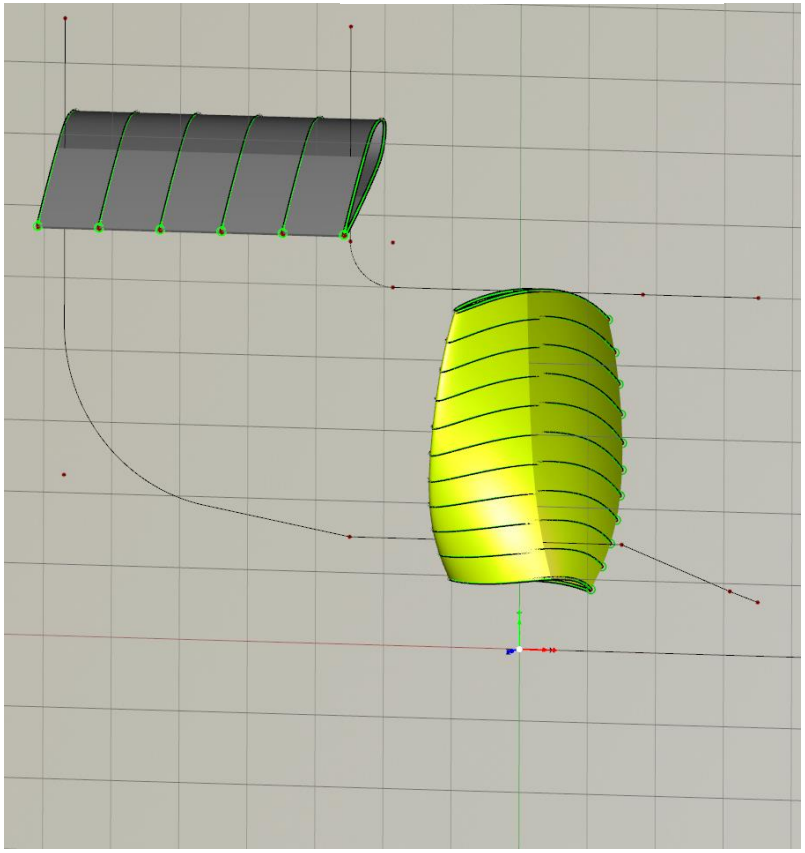


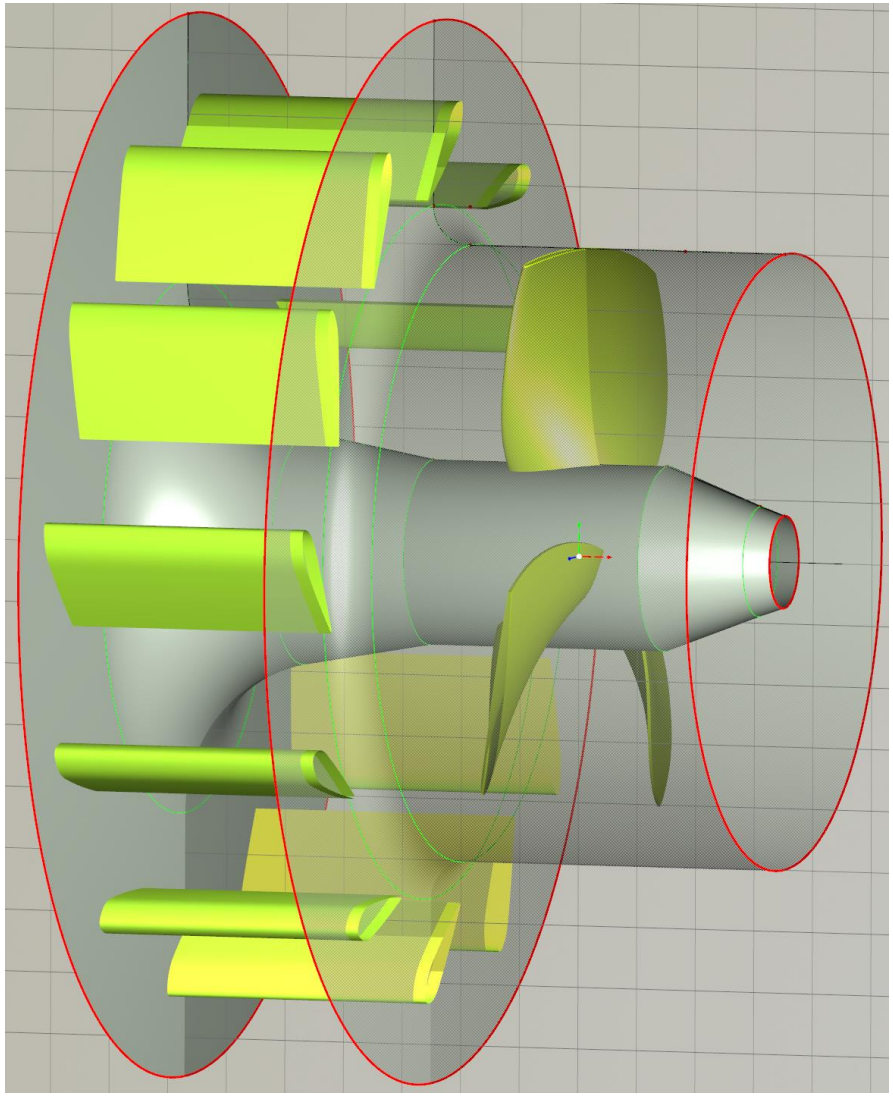
Definition of hydraulic contour

approx. 14 parameters

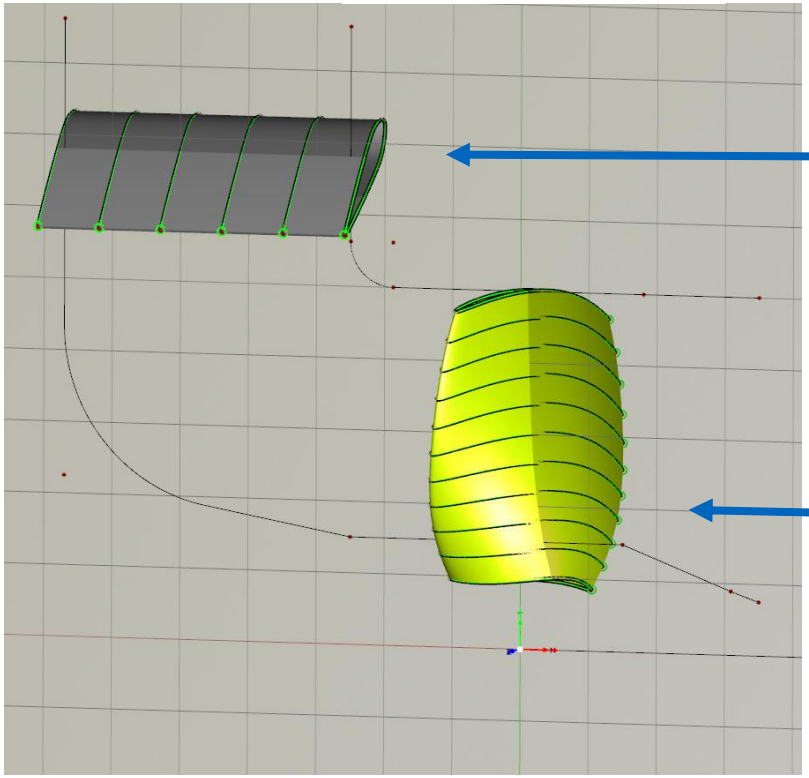
CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

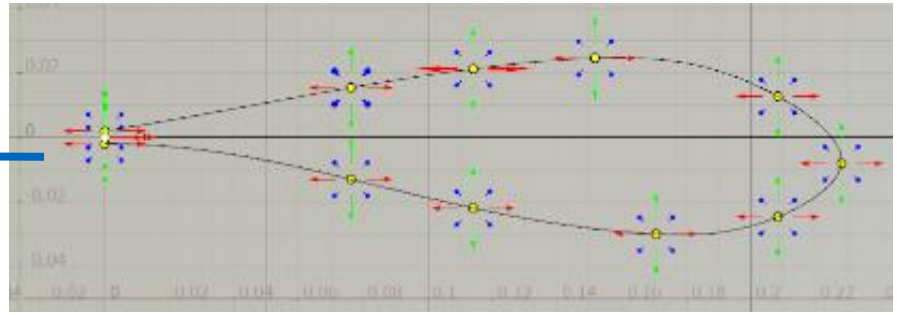
UJEP

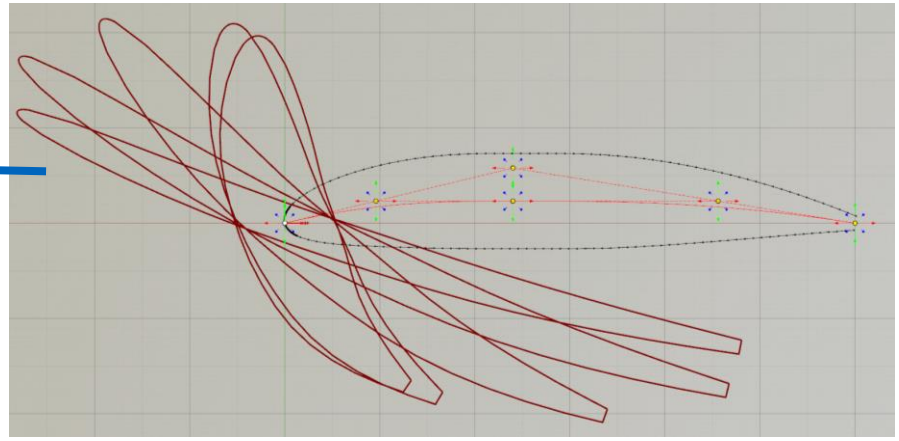




Number of guide vanes and runner blades
1+1 parameter





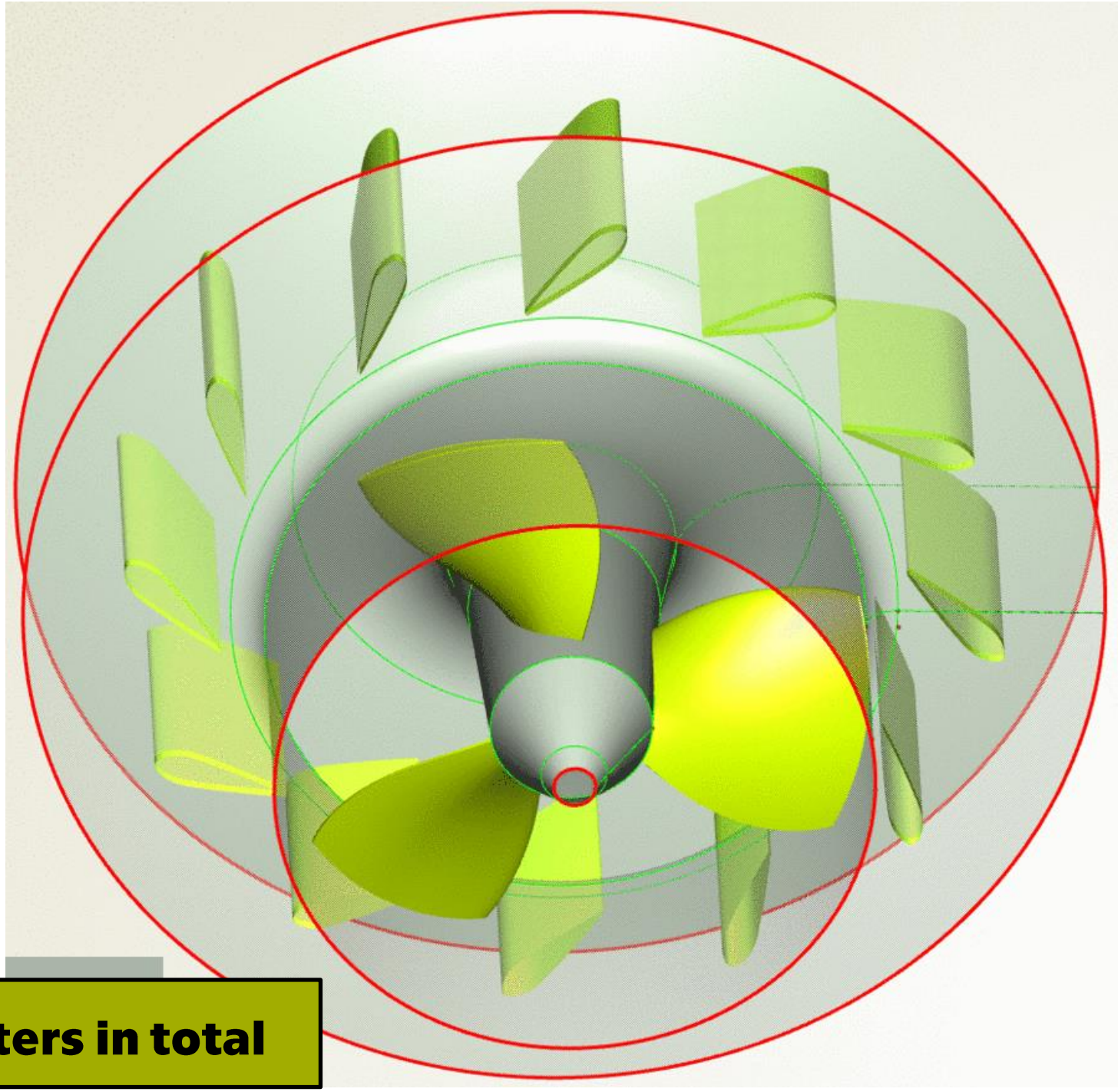


Shape of blades

Guide vanes	**11+1 parameters**
Runner blades	**24+1 parameters**

CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

UJEP



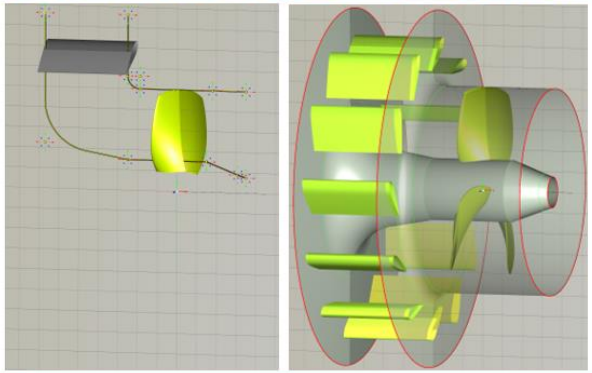
53 parameters in total

CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

UJEP

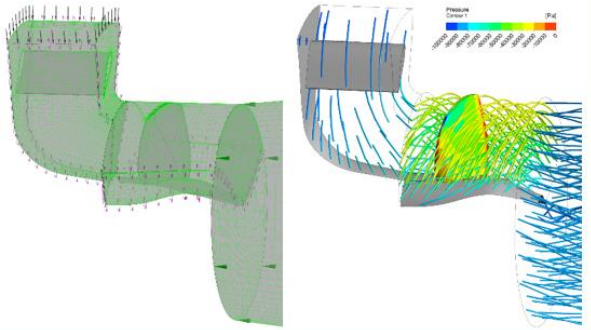
CAESES

PARAMETRIC MODELS OF GEOMETRY



ANSYS
CFX

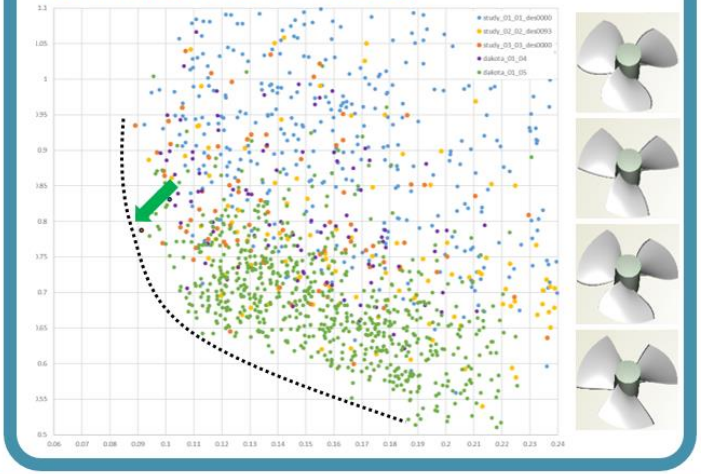
FLUID FLOW ANALYSIS



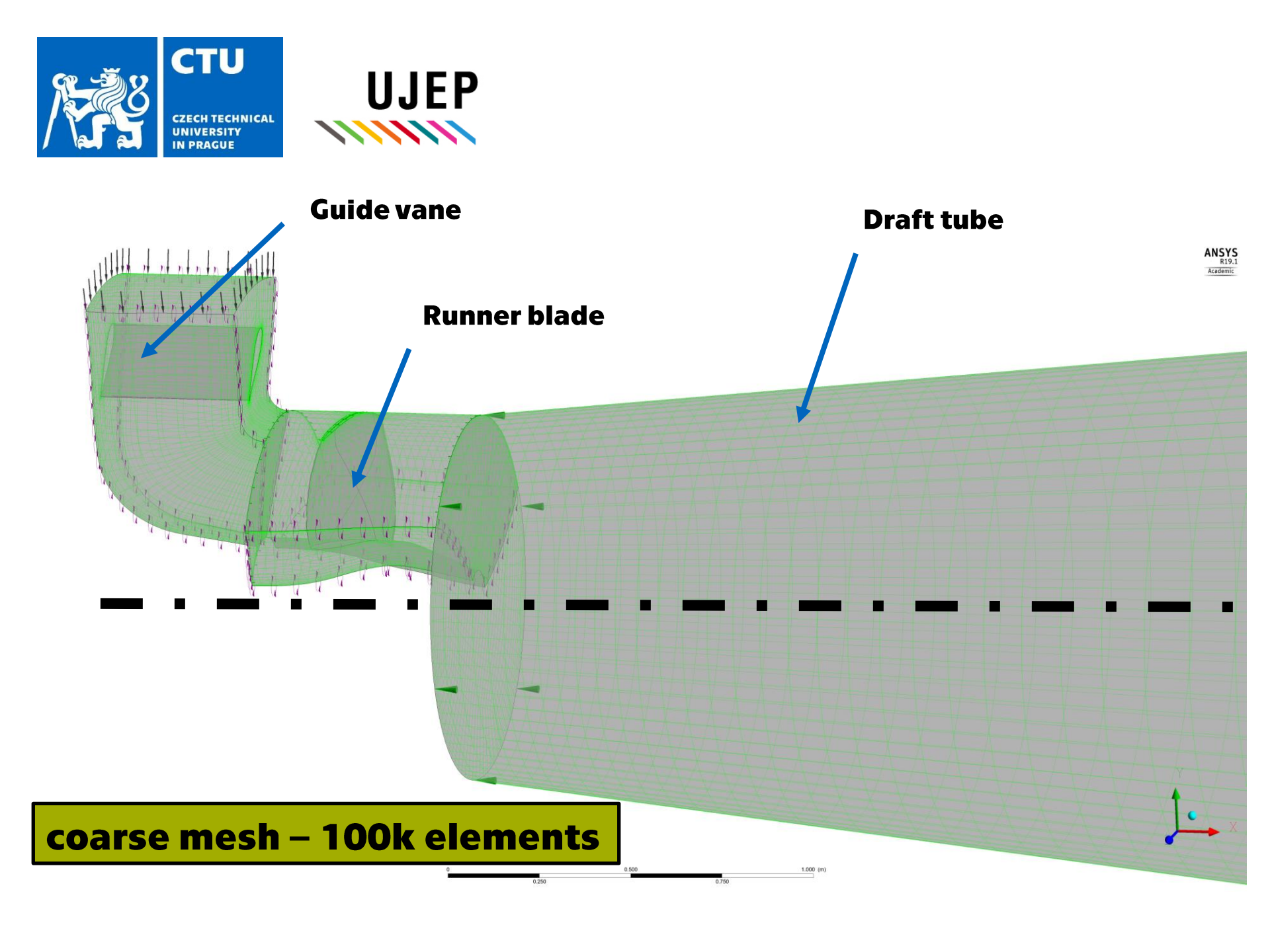
SW CONNECTION

DAKOTA
Explore and predict with confidence.

OPTIMIZATION - MOGA

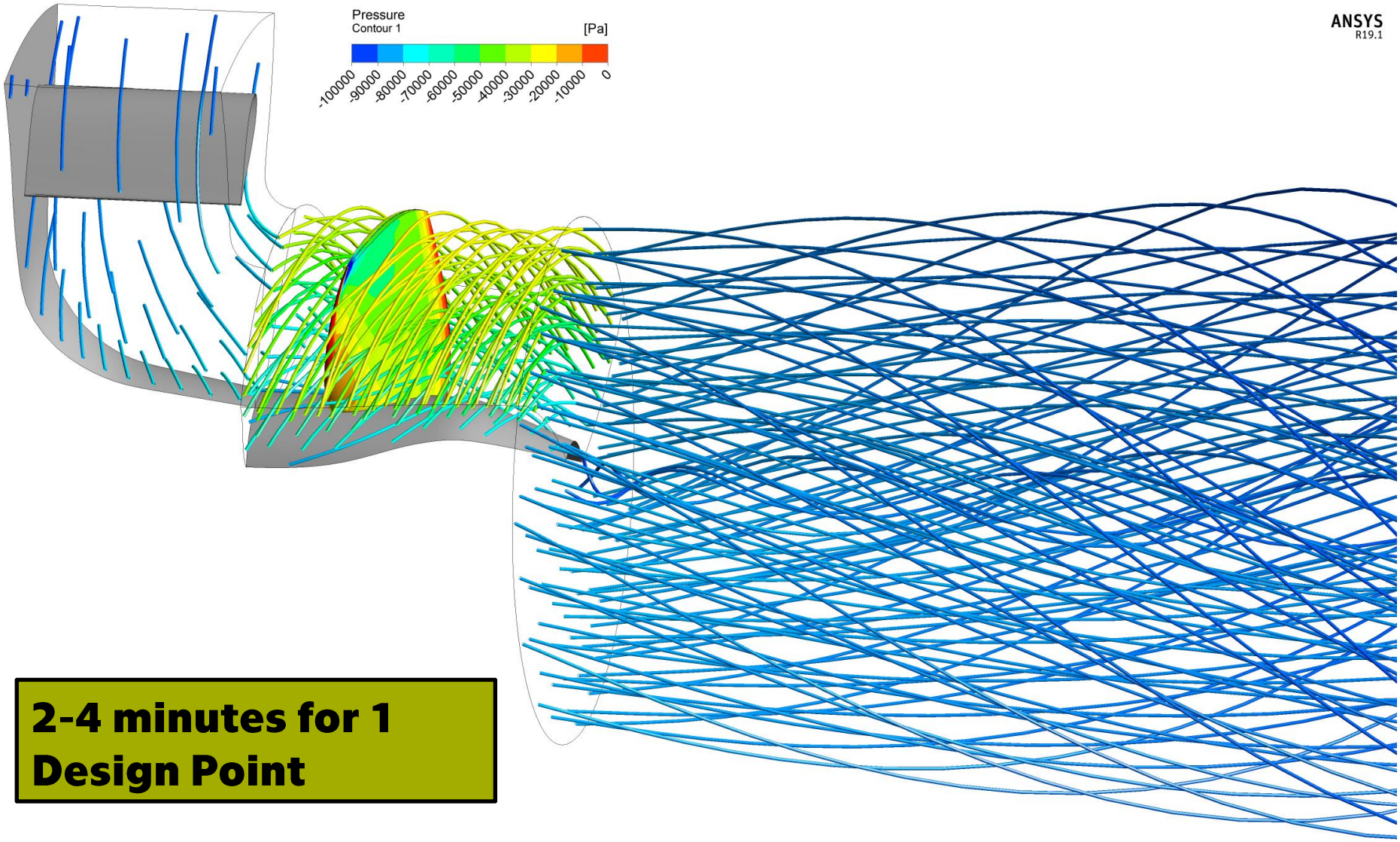


SENSITIVE ANALYSIS


Guide vane
Runner blade
Draft tube
ANSYS
R19.1
Academic
coarse mesh – 100k elements

CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

UJEP



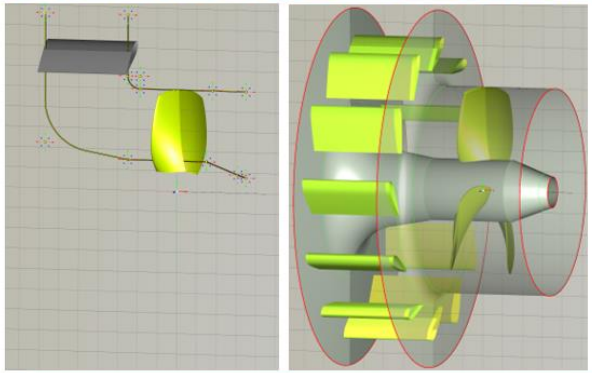
2-4 minutes for 1 Design Point

CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

UJEP

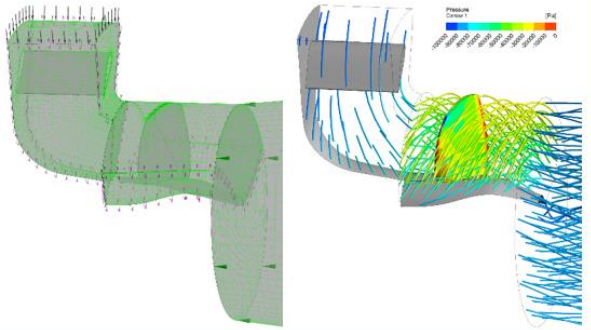
CAESES

PARAMETRIC MODELS OF GEOMETRY



ANSYS
CFX

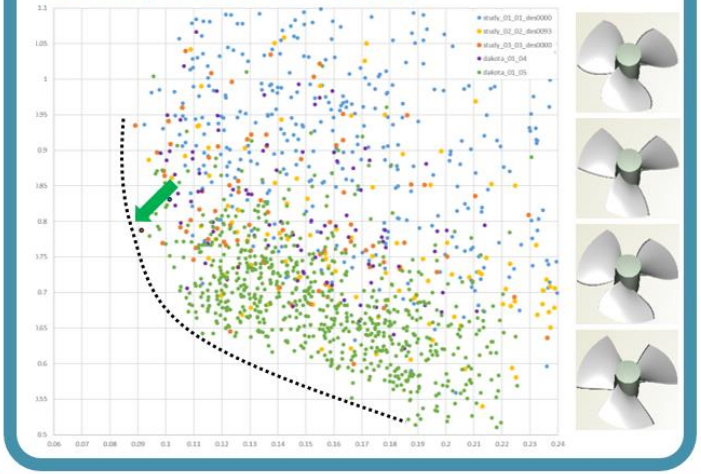
FLUID FLOW ANALYSIS



SW CONNECTION

DAKOTA
Explore and predict with confidence.

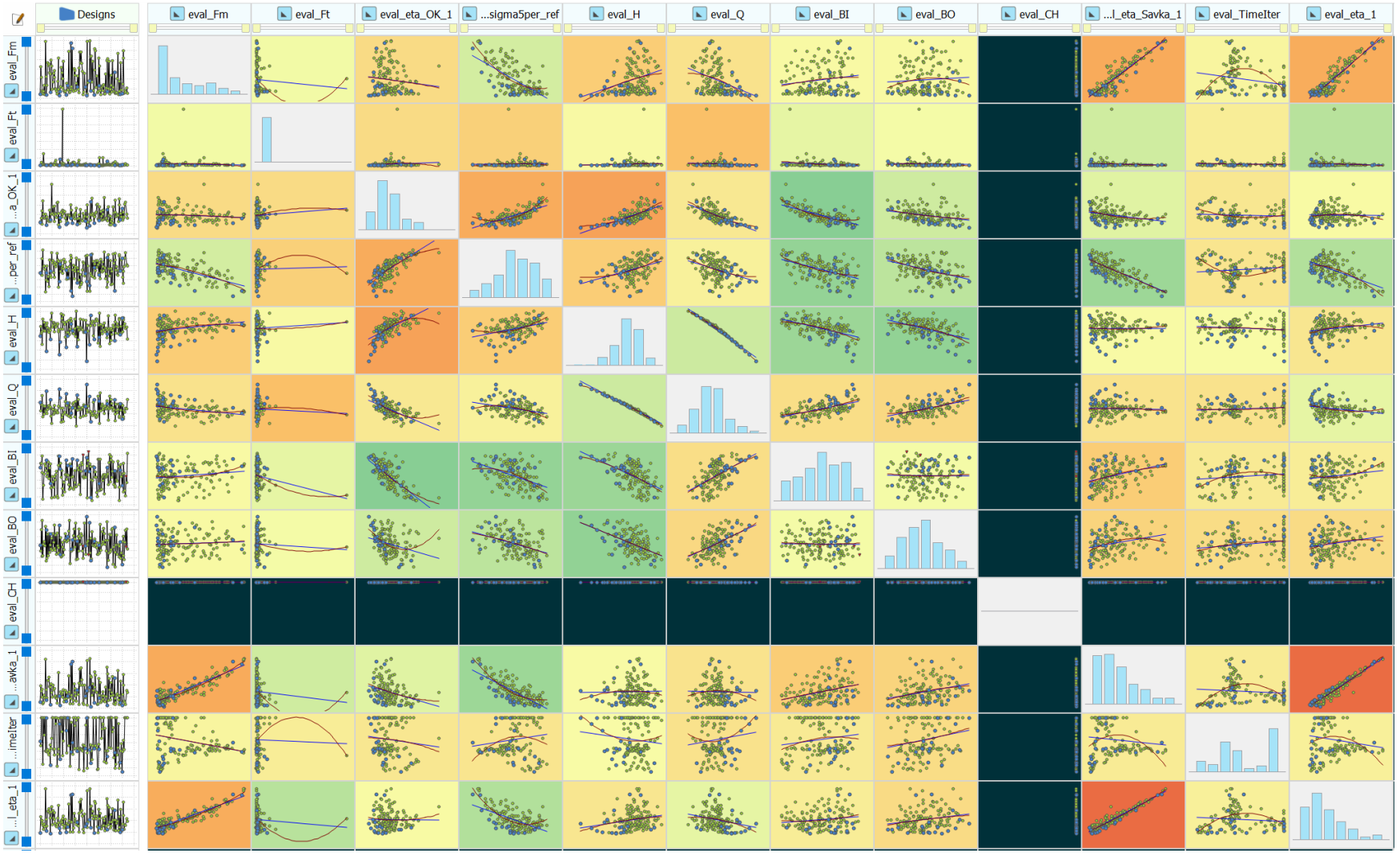
OPTIMIZATION - MOGA



SENSITIVE ANALYSIS

CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

UJEP



CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

UJEP

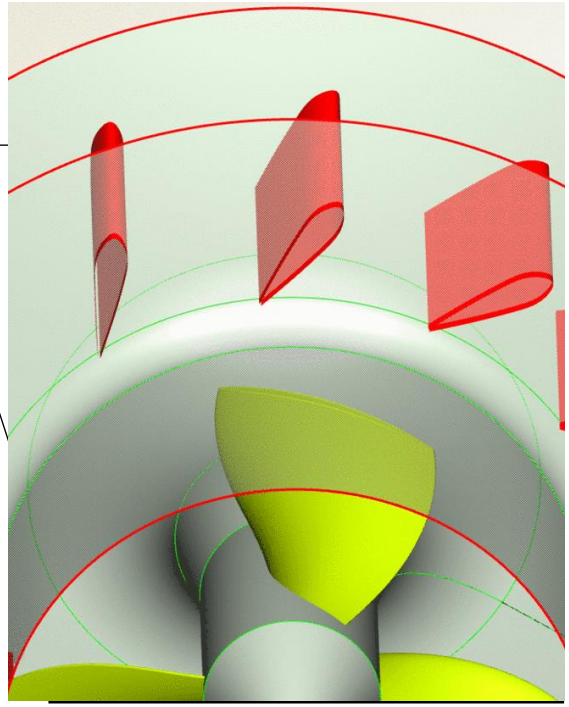
sensitivity analysis

design and strength requirements

previous experience

9 parameters free (of 53 in total)

guide vanes rotation (1 parameter)



CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

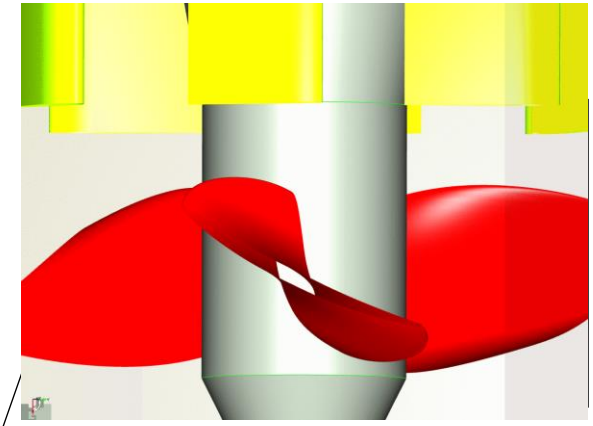
UJEP

sensitivity analysis

design and strength requirements

previous experience

9 parameters free (of 53 in total)



runner blade inlet angle (4 parameters)

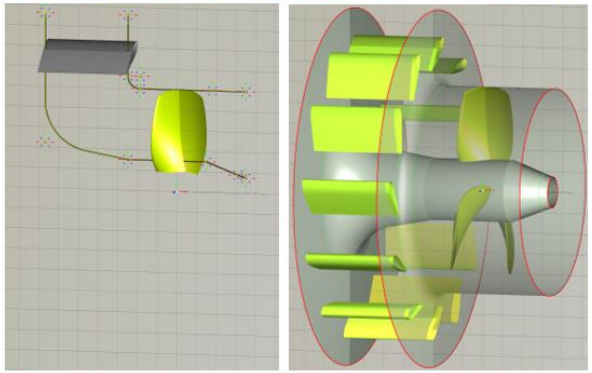
runner blade outlet angle (4 parameters)

CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

UJEP

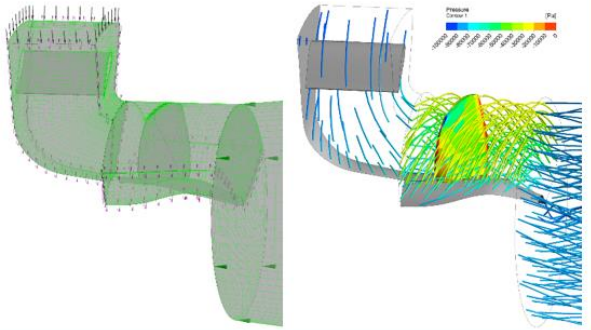
CAESES

PARAMETRIC MODELS OF GEOMETRY



ANSYS
CFX

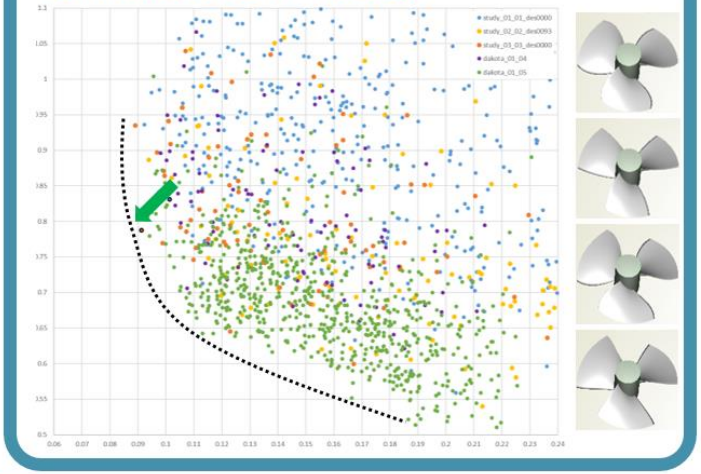
FLUID FLOW ANALYSIS



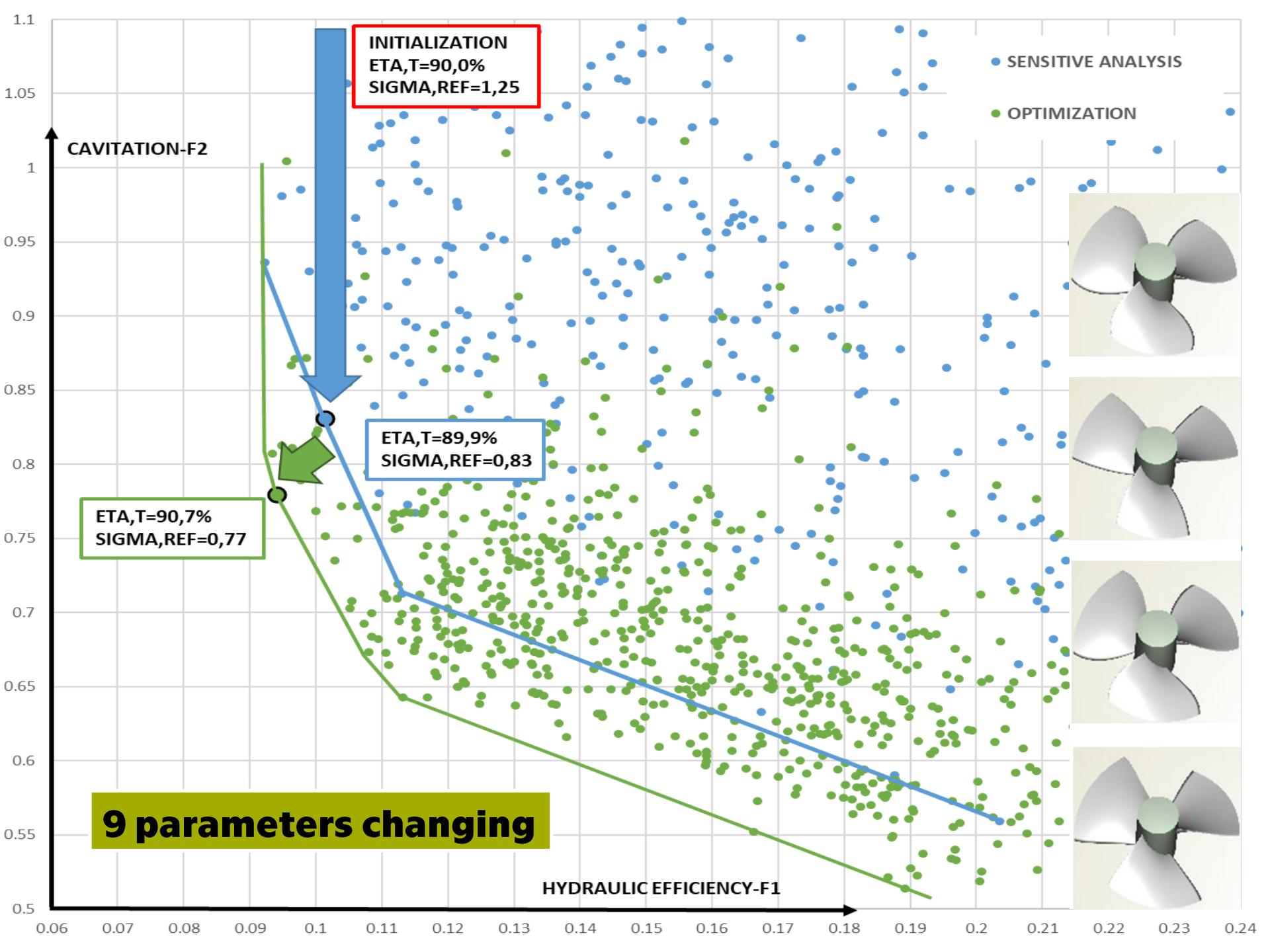
SW CONNECTION

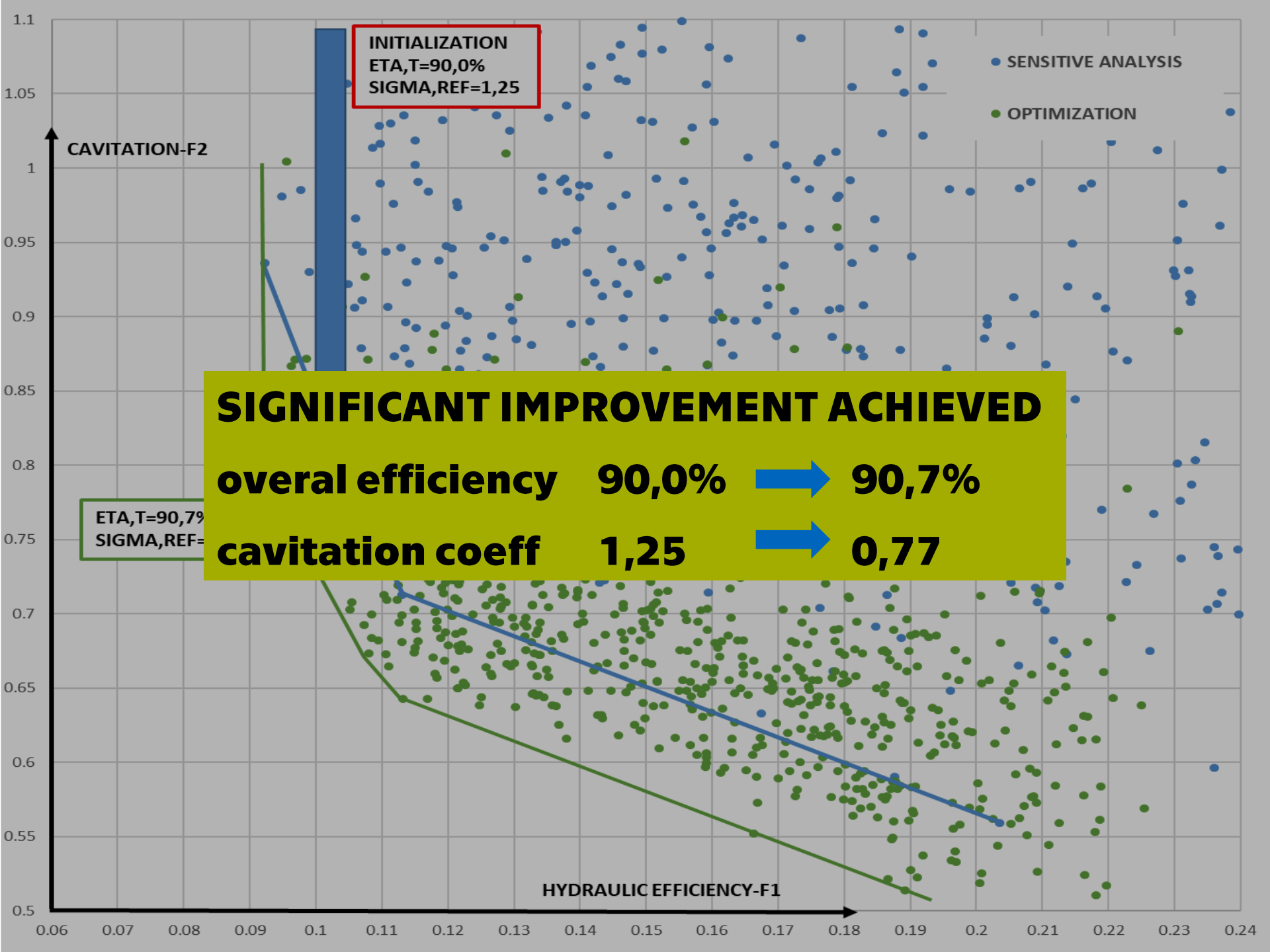
DAKOTA
Explore and predict with confidence.

OPTIMIZATION - MOGA



SENSITIVE ANALYSIS


INITIALIZATION
ETA,T=90,0%
SIGMA,REF=1,25
SENSITIVE ANALYSIS
OPTIMIZATION
CAVITATION-F2
ETA,T=89,9%
SIGMA,REF=0,83
ETA,T=90,7%
SIGMA,REF=0,77
9 parameters changing
HYDRAULIC EFFICIENCY-F1
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.06
0.07
0.08
0.09
0.1
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.2
0.21
0.22
0.23
0.24


INITIALIZATION
ETA,T=90,0%
SIGMA,REF=1,25
SENSITIVE ANALYSIS
OPTIMIZATION
CAVITATION-F2
HYDRAULIC EFFICIENCY-F1
ETA,T=90,7%
SIGMA,REF=
SIGNIFICANT IMPROVEMENT ACHIEVED
overal efficiency 90,0% 90,7%
cavitation coeff 1,25 0,77
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.06
0.07
0.08
0.09
0.1
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.2
0.21
0.22
0.23
0.24

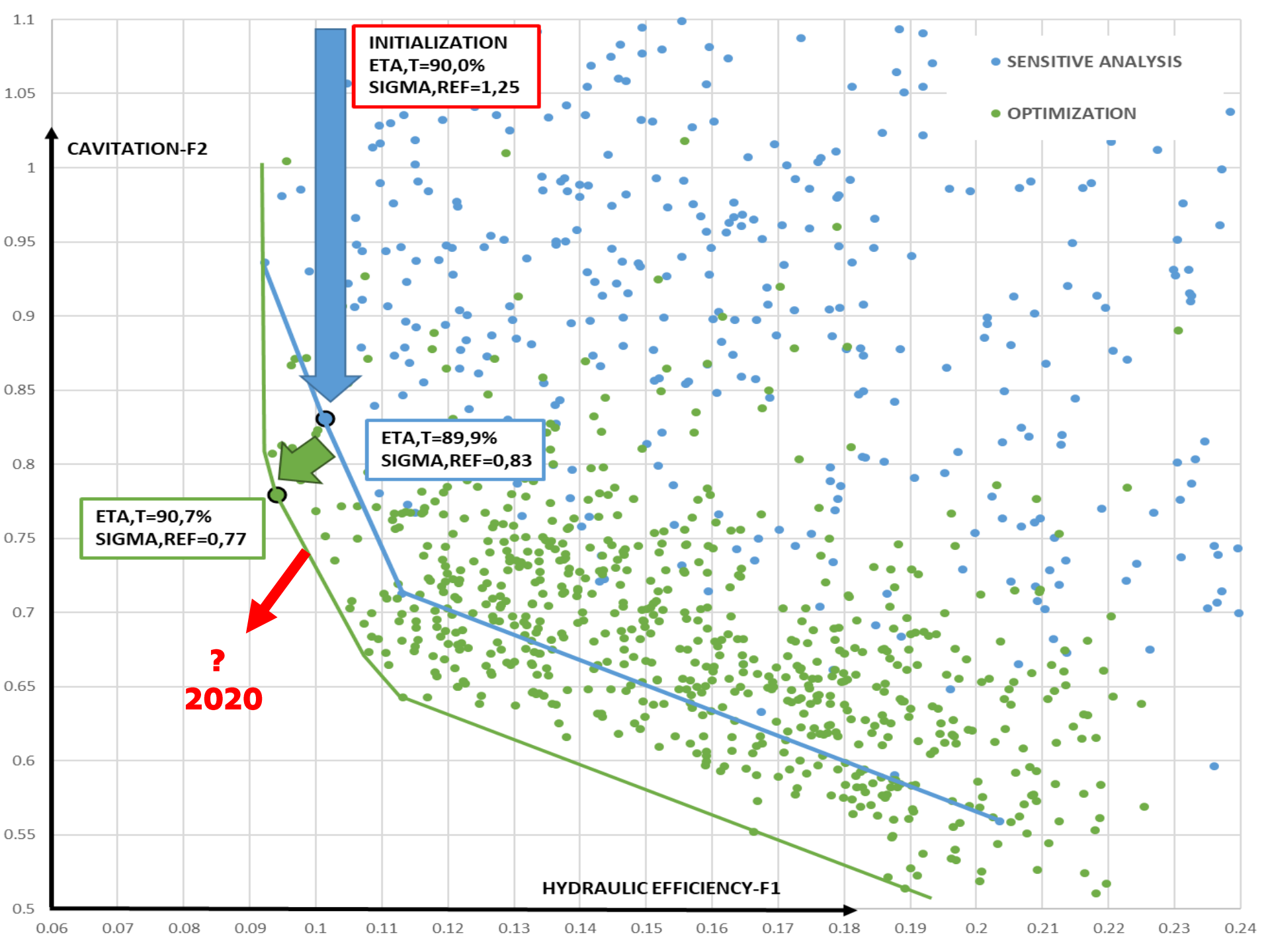
CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

UJEP

VERIFICATION OF CHOOSEN DESIGN

- confirmation of results on the fine mesh
- behavior of turbine in wider operating range
- verification of required parameters (Q_{11}, n_{11}, n_q)
- structural analysis
- prototype testing

RE-DESIGN ?


INITIALIZATION
ETA,T=90,0%
SIGMA,REF=1,25
ETA,T=89,9%
SIGMA,REF=0,83
ETA,T=90,7%
SIGMA,REF=0,77
?
2020
SENSITIVE ANALYSIS
OPTIMIZATION
CAVITATION-F2
HYDRAULIC EFFICIENCY-F1
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.06
0.07
0.08
0.09
0.1
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.2
0.21
0.22
0.23
0.24