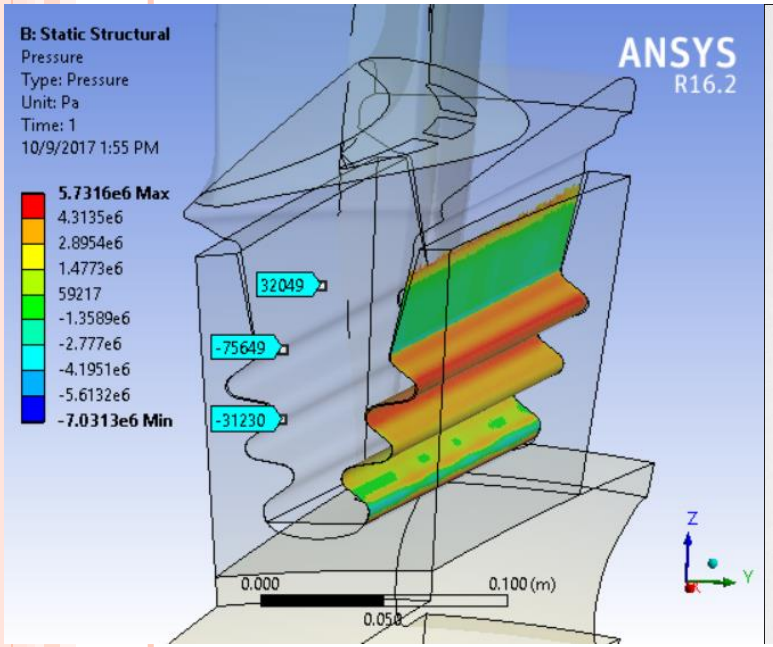
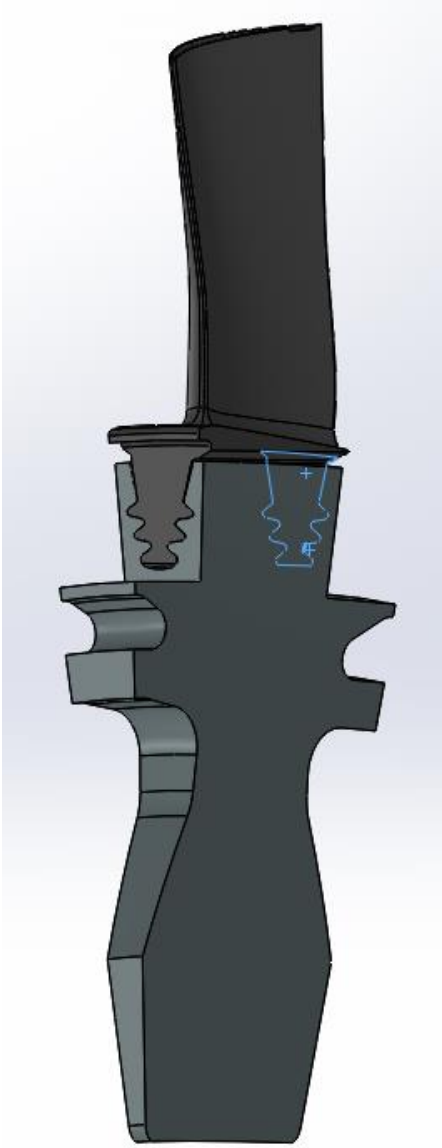


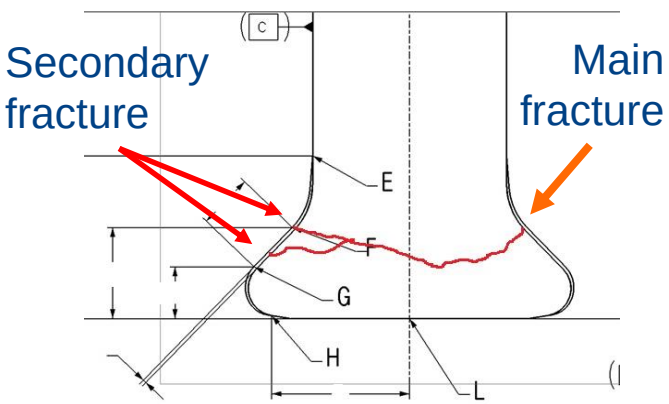
Development of advanced criteria for blade root design and optimization

Farhad Alinejad
No. S221058
Under supervision of
Prof. Daniele Botto

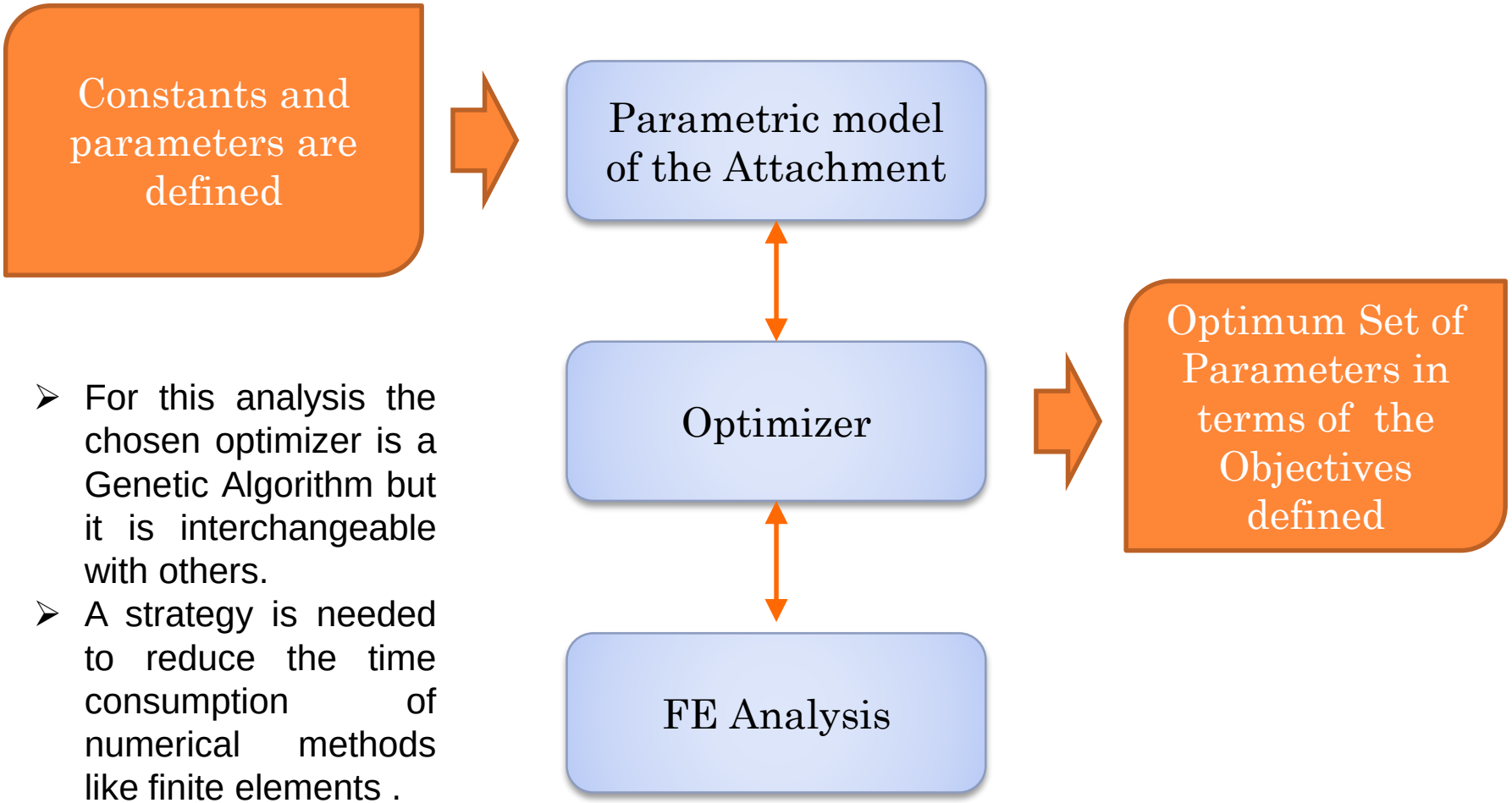
INTRODUCTION



- The aim is to
  - Apply some complex profiles and different dimensions
  - Respond to “what ifs”
  - Decrease the high cost analysis
  - Exploit the material strength
  - Provide robust solutions
- The Strategies are:
  - Defining the parametric attachment model.
  - Applying Meta model in Optimization
  - Minimizing the stress state in critical areas.

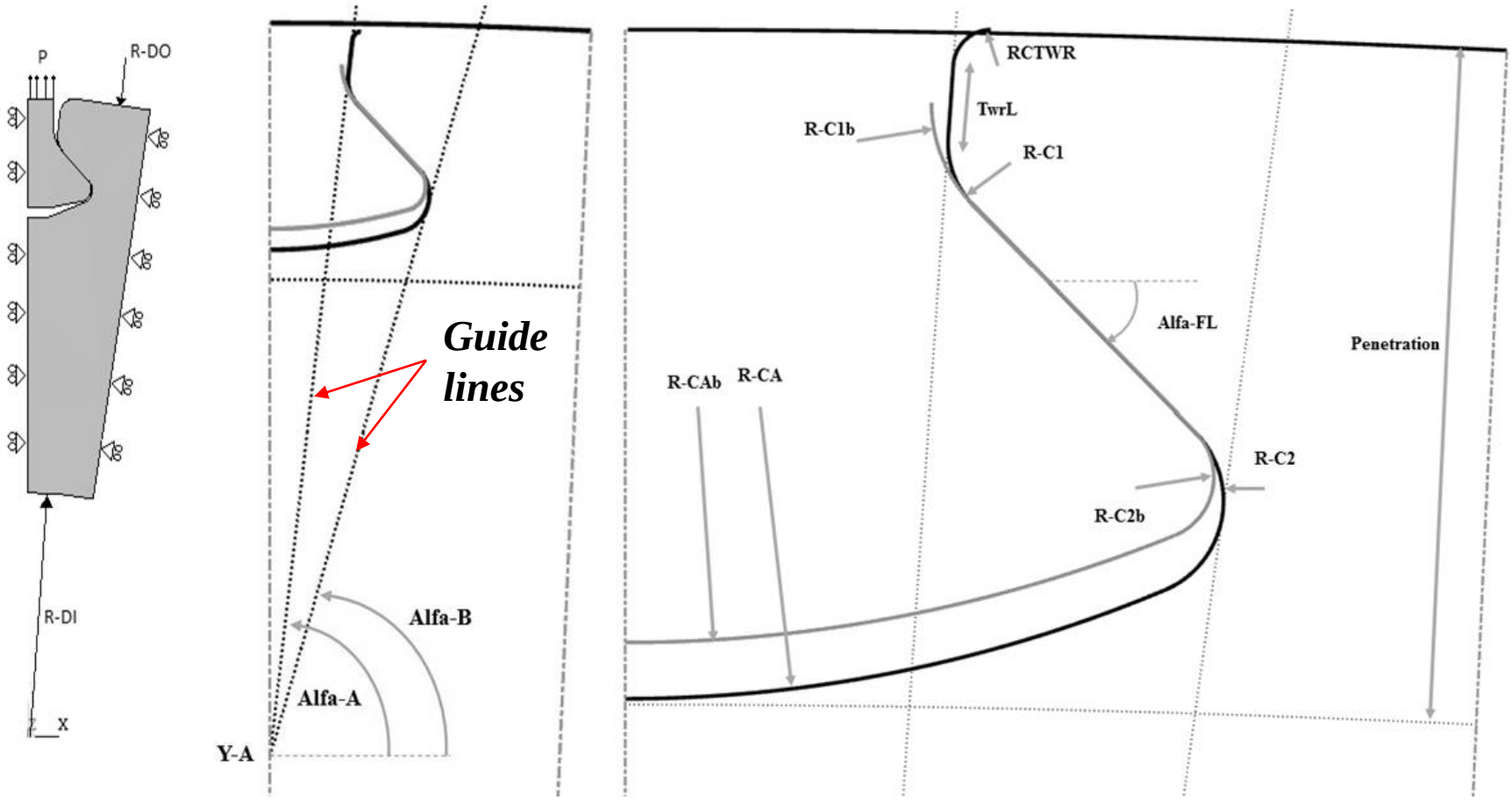


Process Outline



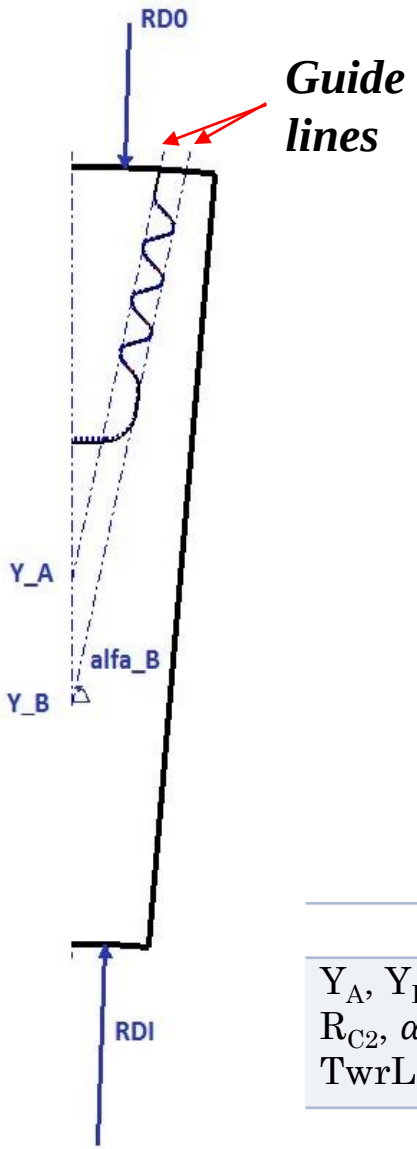
- For this analysis the chosen optimizer is a Genetic Algorithm but it is interchangeable with others.
- A strategy is needed to reduce the time consumption of numerical methods like finite elements .

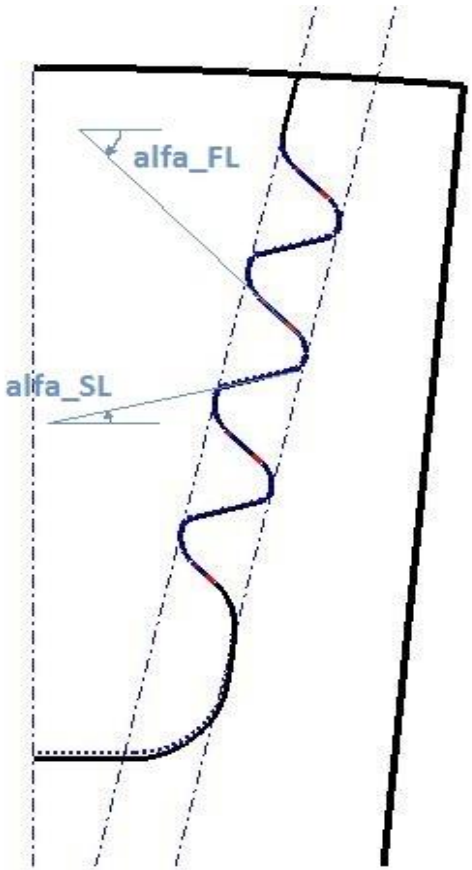
Parametric description - Dovetail

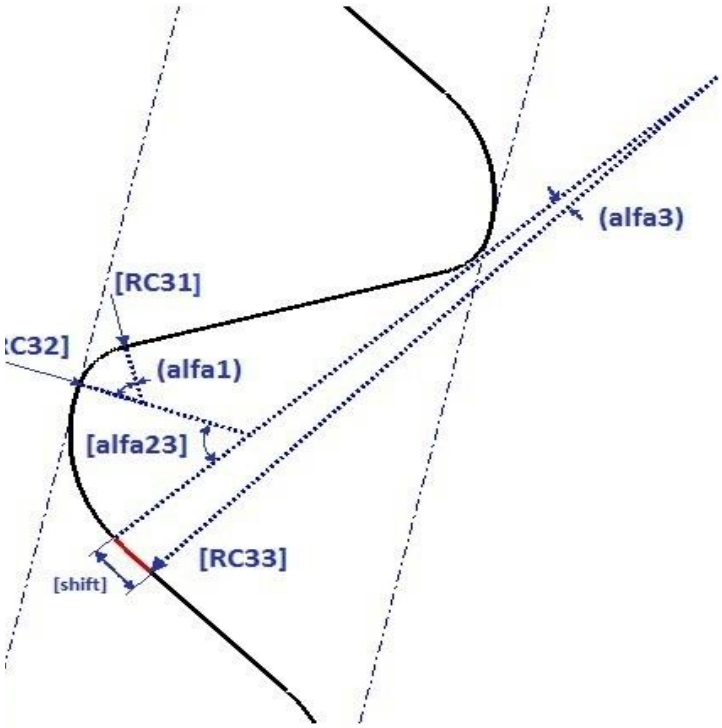


Parameters	Constants
Y_A, Y_B, α_A , α_B, R_{C1}, R_{C1b}, R_{C2b}, R_{C2}, α_{FL}, R_{CA}, R_{CAb}, R_{CTWR}, TwrL, R_{C1b},	TotalNumberofBlades, R_{DO}, R_{DI}, ω, Penetration, Mass of the blade.

PARAMETRIC GEOMETRY – Firtree







Parameters	Constants
Y_A, Y_B, α_A , α_B, R_{C1}, R_{C1b}, R_{C2b}, R_{C2}, α_{FL}, α_{SL}, R_{CA}, R_{CAb}, R_{CTWR}, TwrL, R_{C3}, R_{C3b}, R_{C4}, R_{C4b}.	TotalNumberofBlades, RDO, RDI, ω, Penetration, Mass of the blade.

Dimension of the problem

- Dovetail

Number of Parameters: 10

The minimum number of divisions for every parameter range: 50

The minimum time for FE evaluation of every trial with a common PC: 15 seconds

Total time for evaluating all possible Geometries:

$10^{50} \times 15 = 1.5e51$ seconds

= 1.7e46 days

= **4.7e43 Years**

- Firtree (with 4 teeth)

Number of Parameters: 19

The minimum number of divisions for every parameter range: 50

The minimum time for FE evaluation of every trial with a common PC: 30 seconds

Total time for evaluating all possible Geometries:

$19^{50} \times 30 = 2.6e65$ seconds

= 3e60 days

= **8.24e57 Years**

How old is the universe: **14e9 Years**

Genetic Algorithm

gene

chromosome

P_1^1	P_2^1	P_3^1	P_4^1	P_5^1	P_6^1	P_7^1	P_8^1

PARENT-1

P_1^1	P_2^1	P_3^1	P_4^1

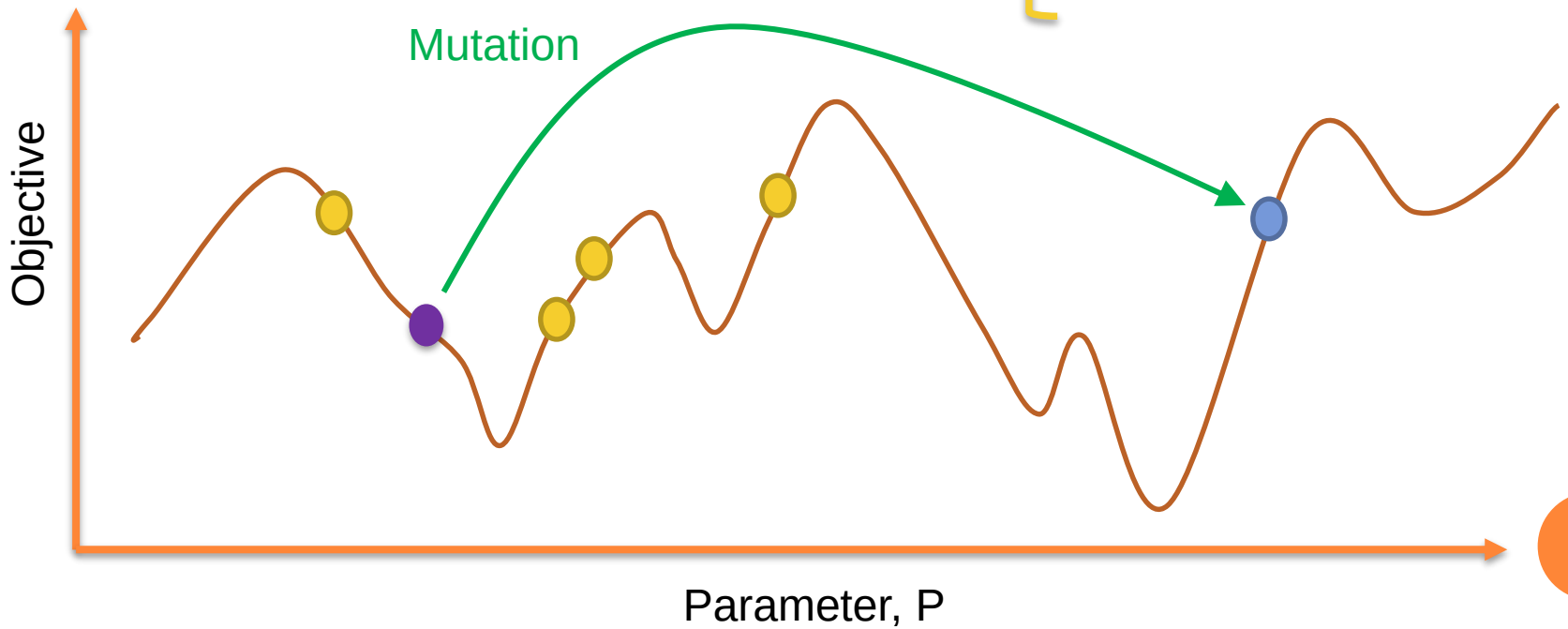
P_5^1	P_6^1	P_7^1	P_8^1

PARENT-2

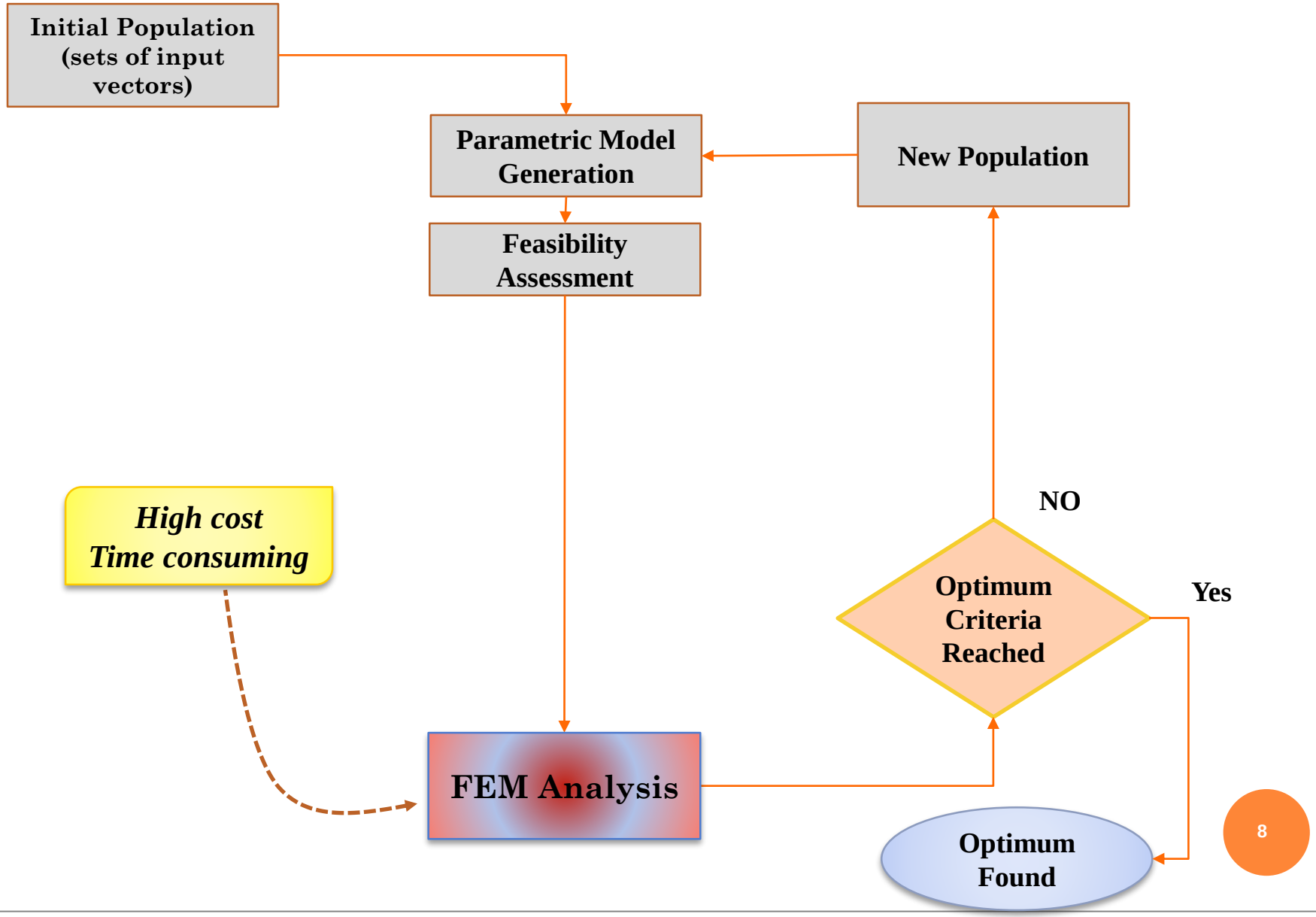
P_1^2	P_2^2	P_3^2	P_4^2	P_5^2	P_6^2	P_7^2	P_8^2

P_1^2	P_2^2	P_3^2	P_4^2

P_5^2	P_6^2	P_7^2	P_8^2



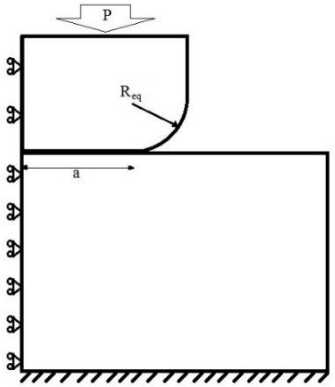
Optimization method – Genetic Algorithm

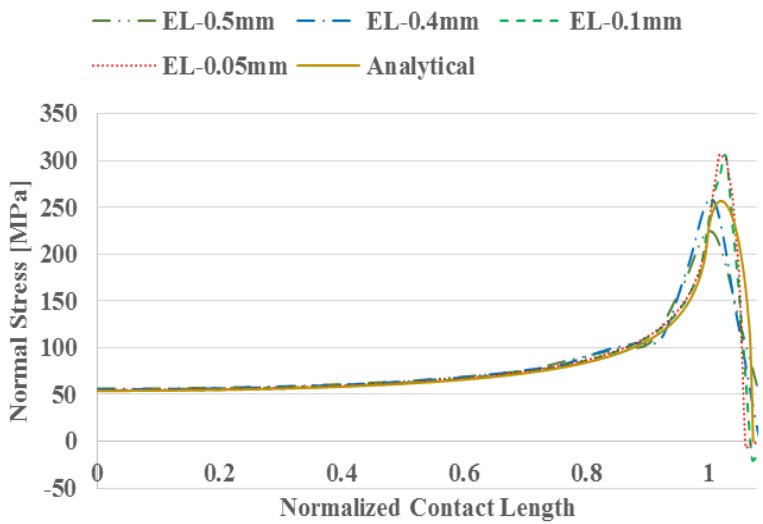


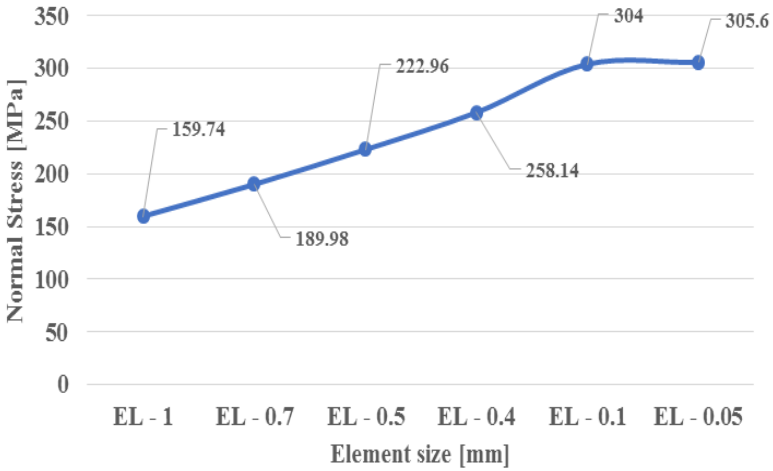
BENCHMARK FOR MESH CONVERGENCE

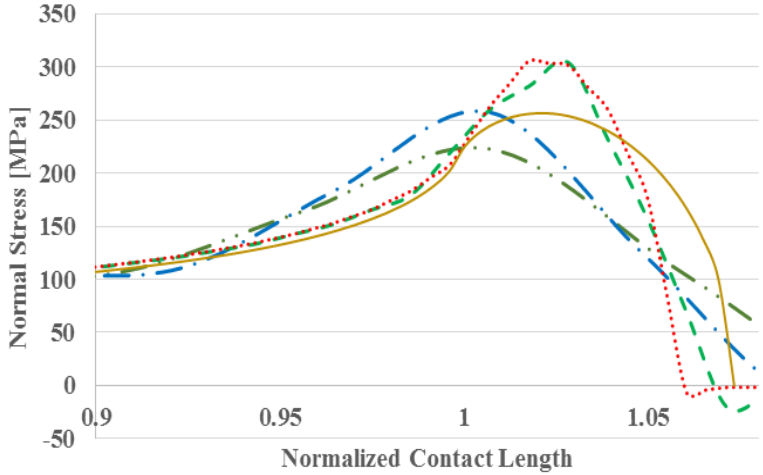
A punch type contact was simulated as a benchmark, to check the mesh convergence and also comparing FE solution with an analytical solution of contact.

The mesh size is kept constant during the optimization procedure





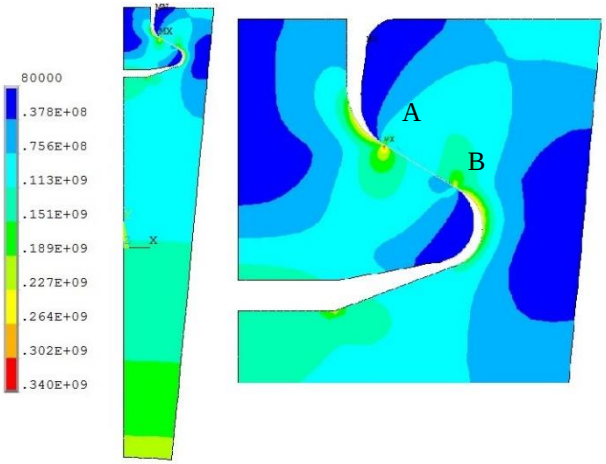


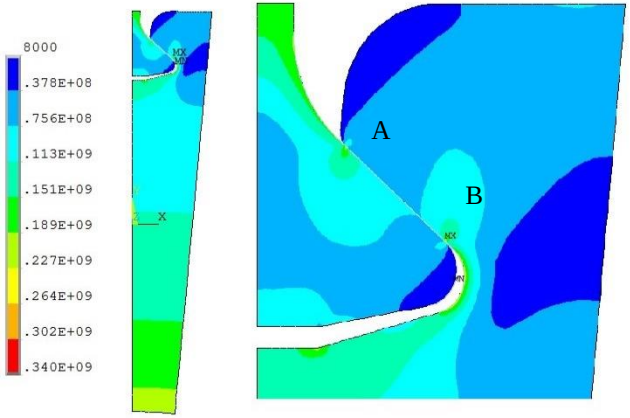


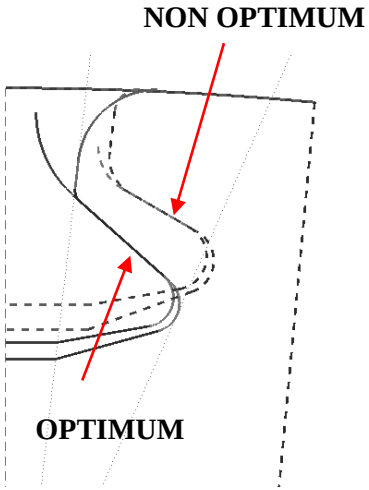
GA OPTIMUM VS. NON-OPTIMUM GEOMETRY (OBJECTIVE: EQV STRESS)

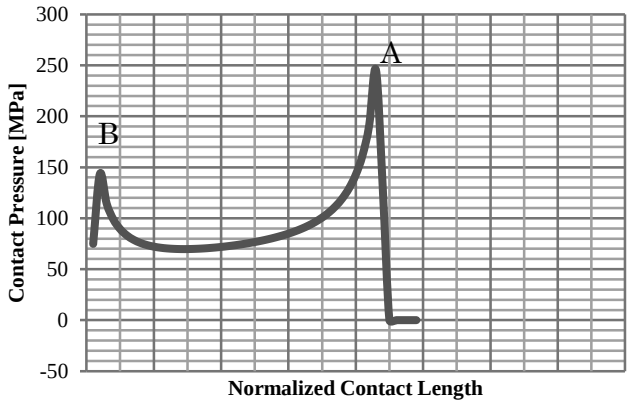
NON-OPT GEOM:
Max σ_{EQV}=336 MPa

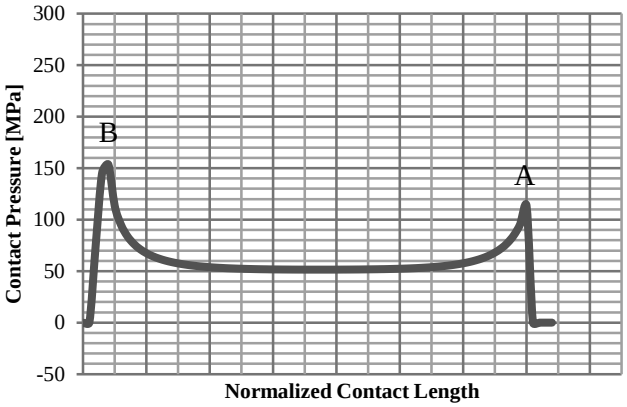
OPTIMUM GEOM:
Max σ_{EQV}=207 MPa





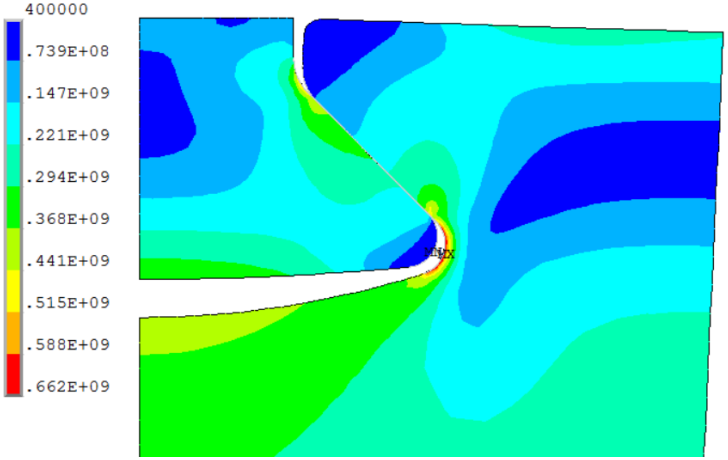




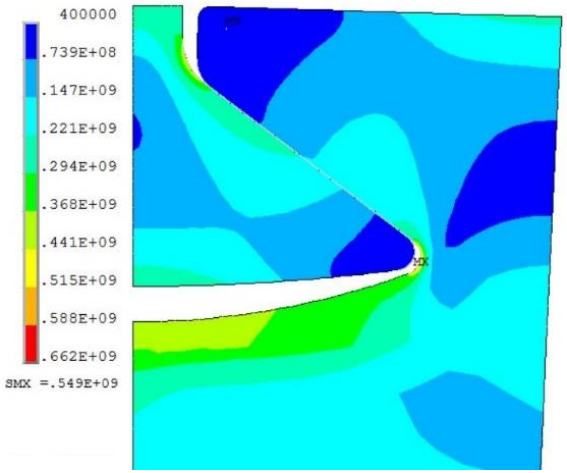


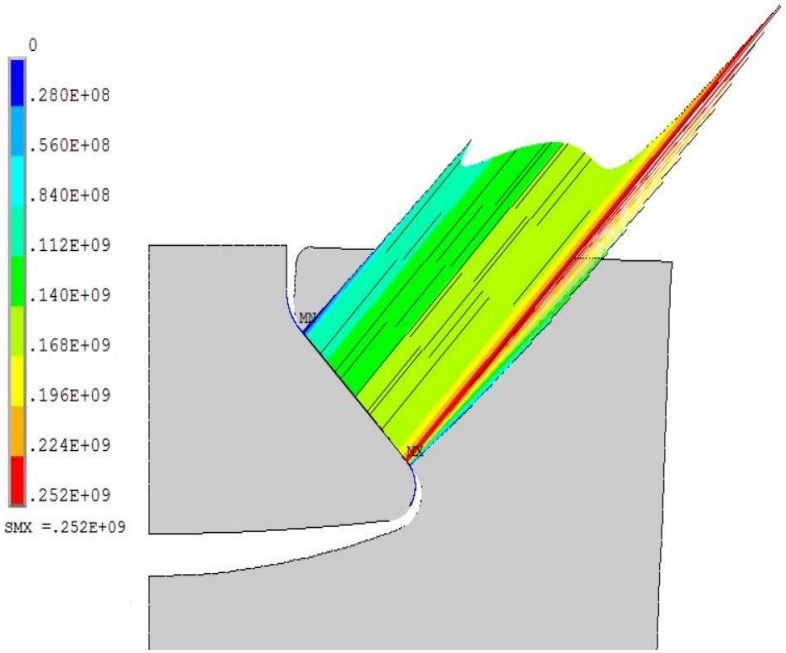
Objective function: contact pressure (Case II)

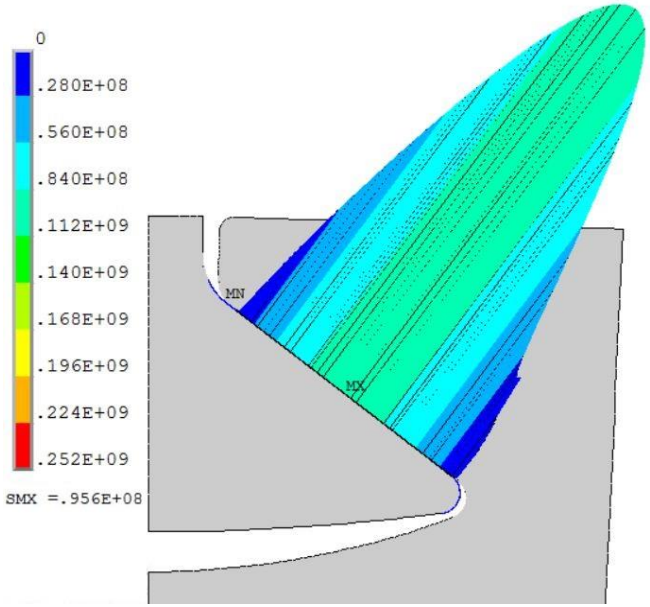
NON OPTIMUM



OPTIMUM







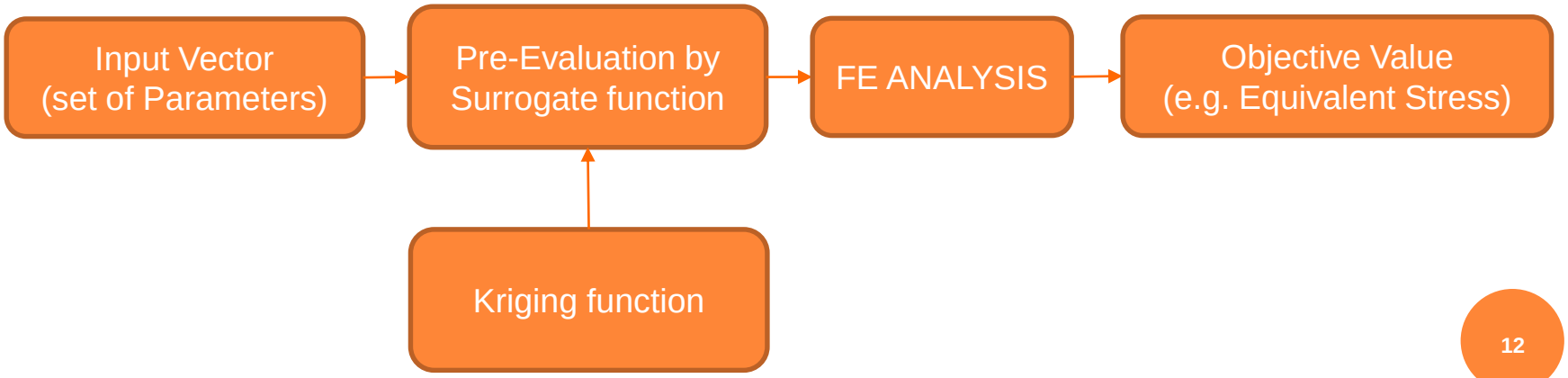
Reducing computational cost

Direct FE Analysis

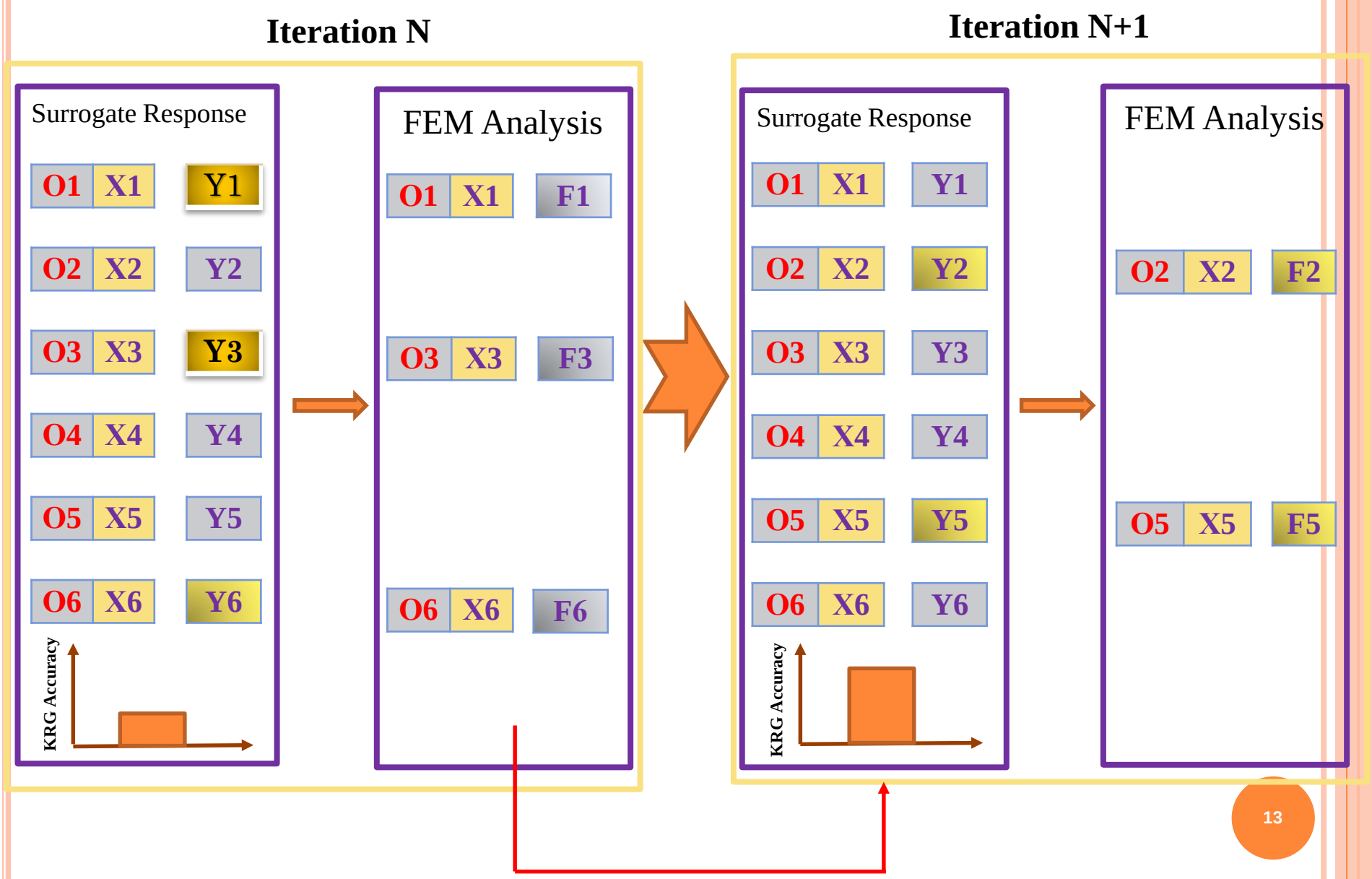
Surrogate Model (Meta-Model)

$y = f(x)$ Where $x: V_{Input}$ and $y: \sigma_{EQV}$

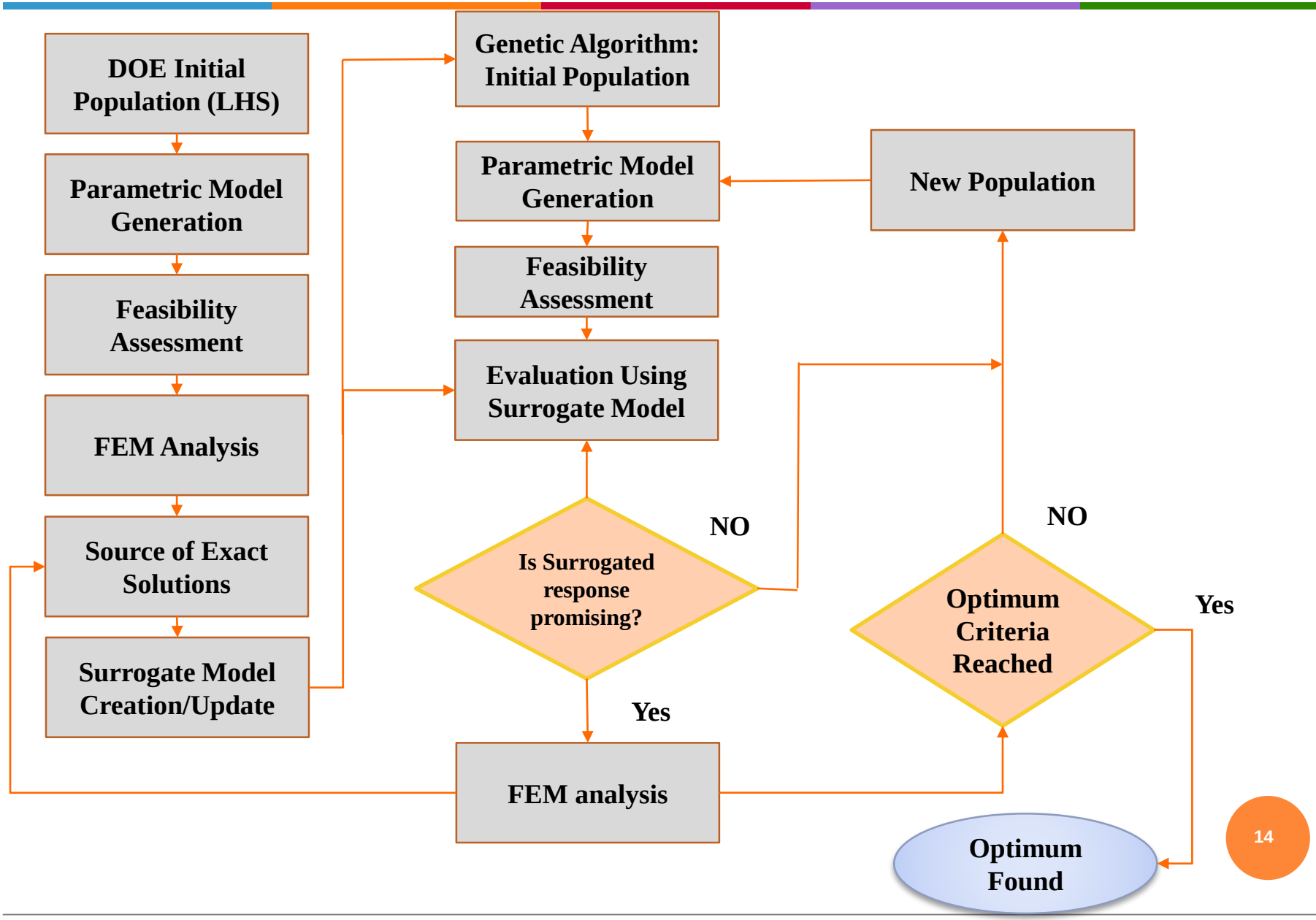
Surrogate Function – FE Analysis



SURROGATION

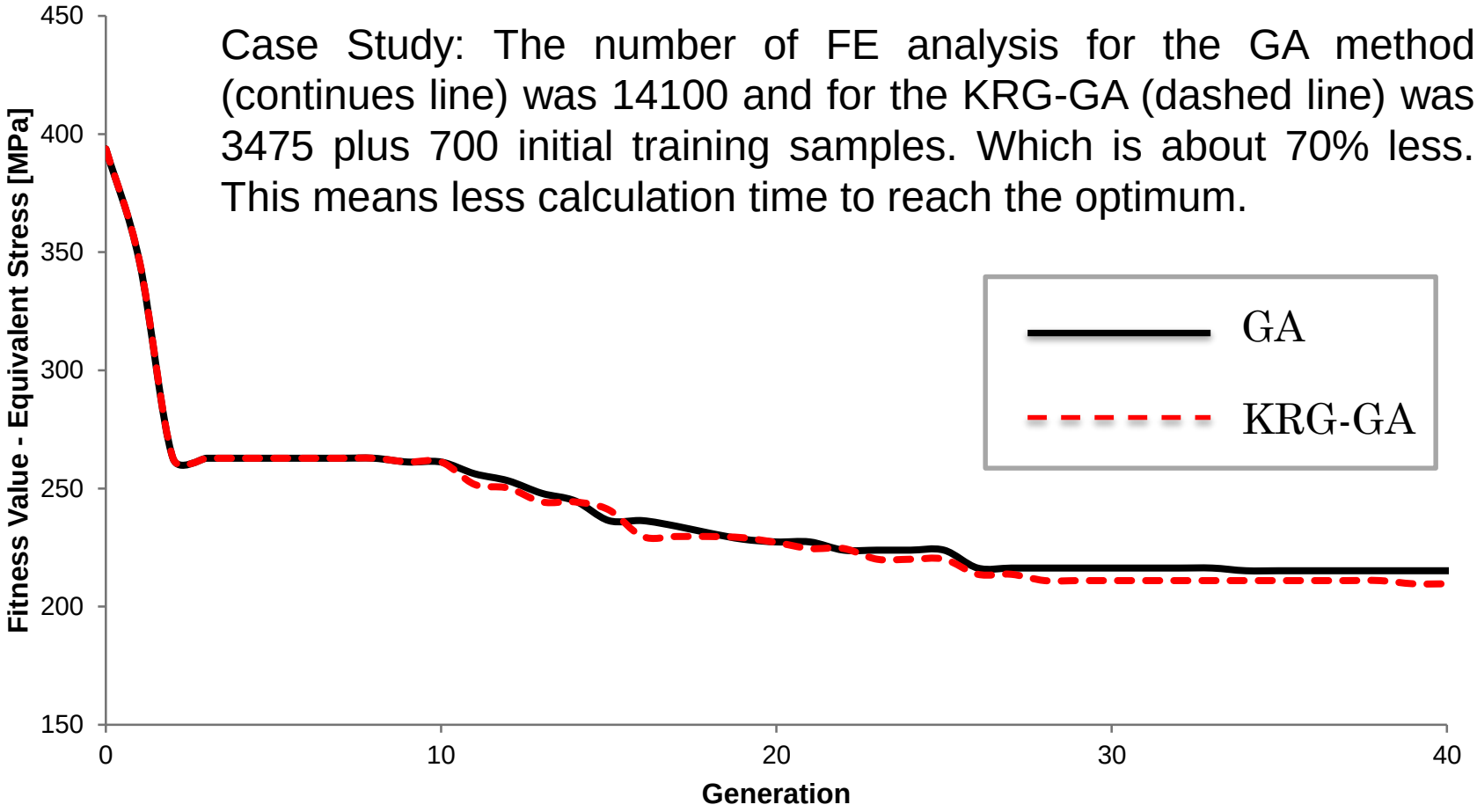


KRG-GA Optimization flowchart



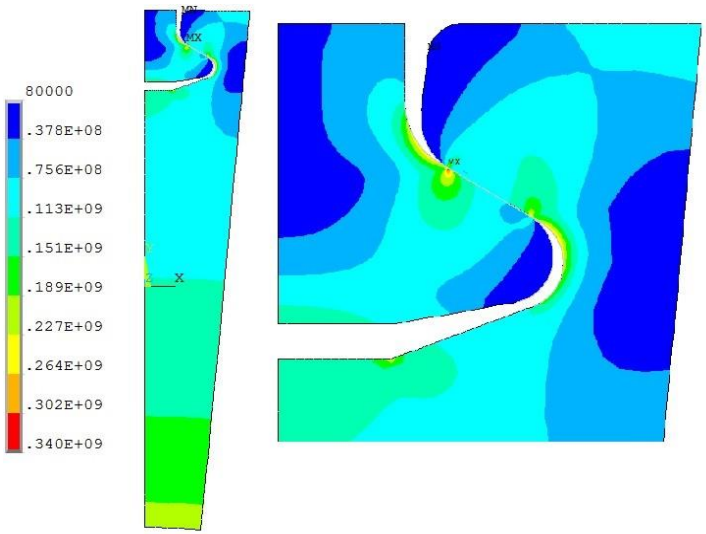
GA vs KRG-GA optimization

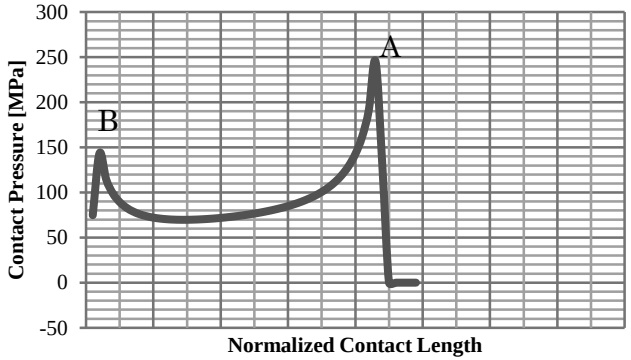
Case Study: The number of FE analysis for the GA method (continues line) was 14100 and for the KRG-GA (dashed line) was 3475 plus 700 initial training samples. Which is about 70% less. This means less calculation time to reach the optimum.



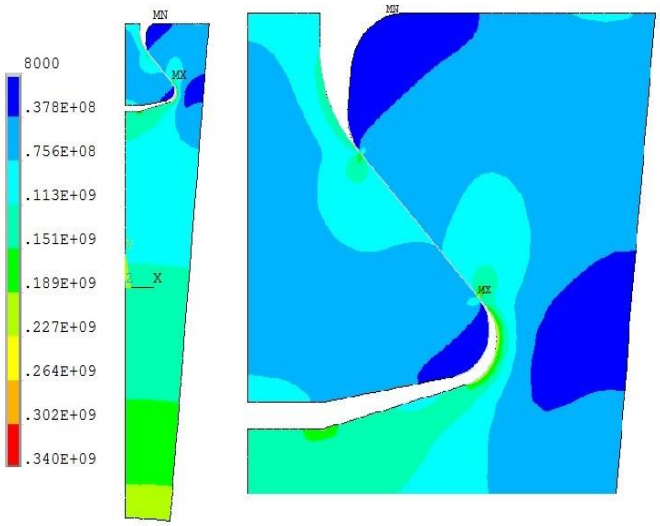
KRG-GA OPTIMUM VS NON-OPTIMUM GEOMETRY

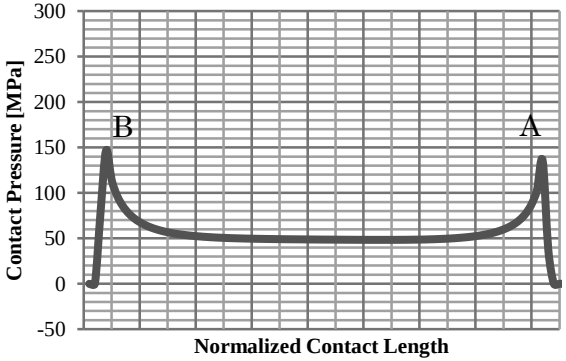
NON-OPT GEOM:
Max σ_{EQV}=339 MPa



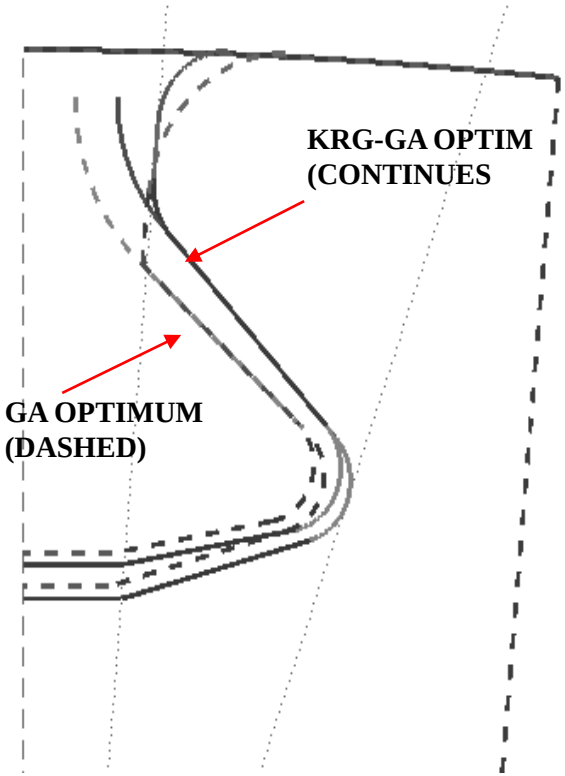


OPTIMUM GEOM:
Max σ_{EQV}=206 MPa

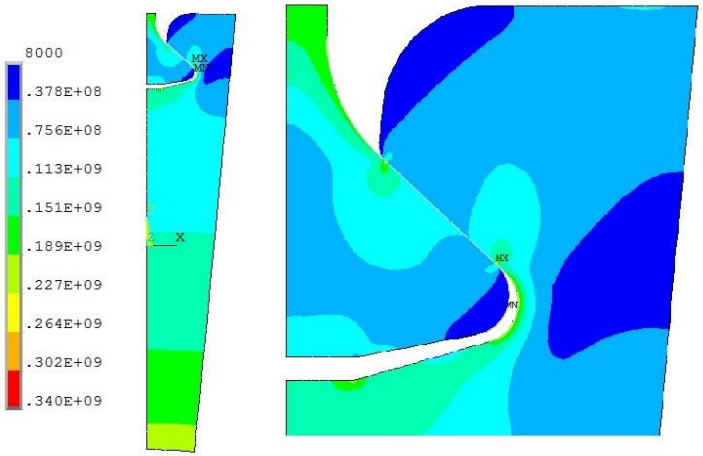




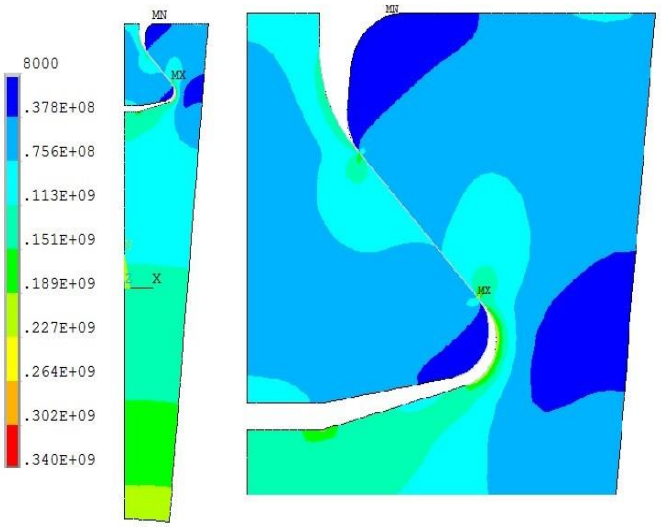
KRG-GA OPTIMUM VS. GA OPTIMUM



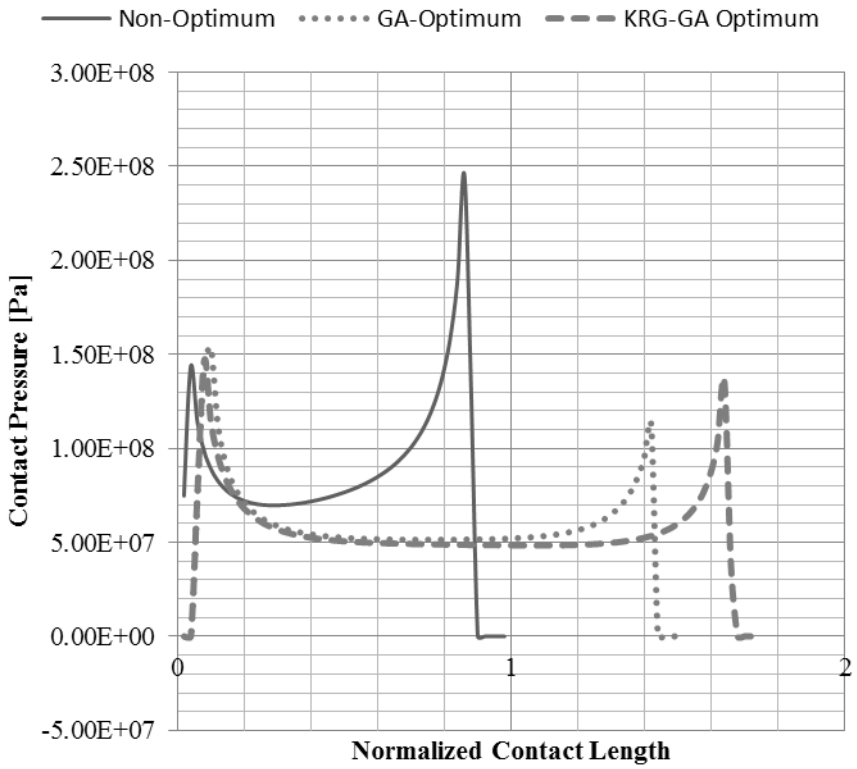
GA OPTIMUM GEOMETRY Max σ_{EQV}=207 (MPa)

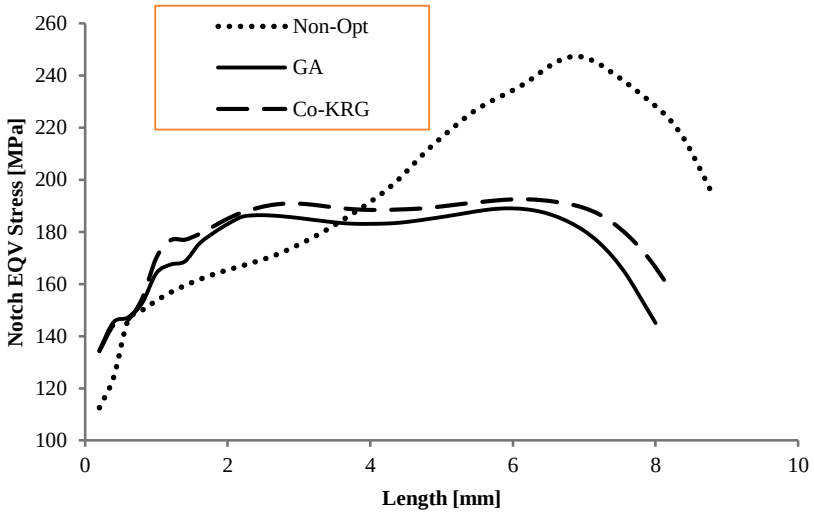


KRG-GA OPTIMUM GEOMETRY Max σ_{EQV}=206 (MPa)

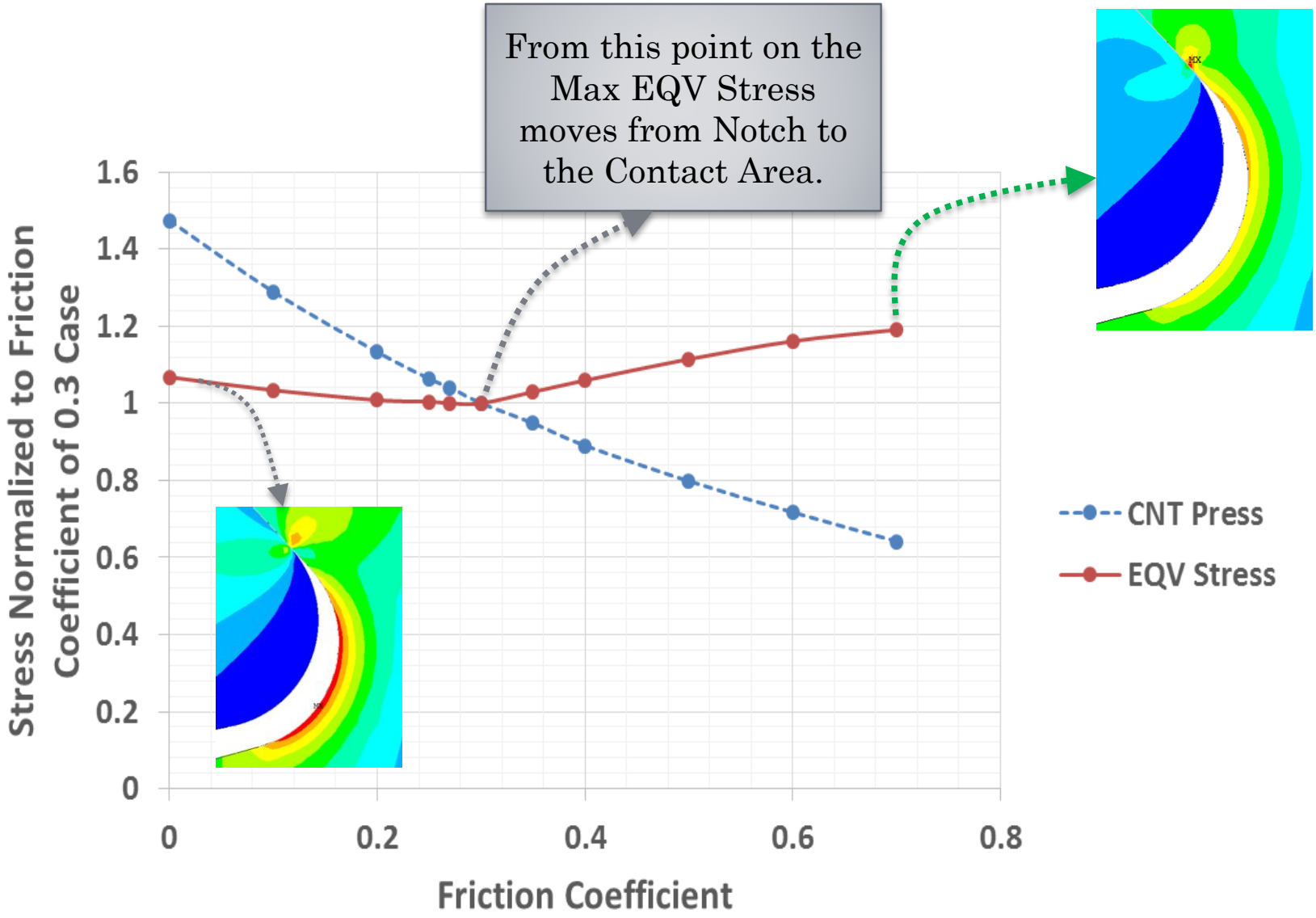


Contact Pressure and Notch equivalent stress

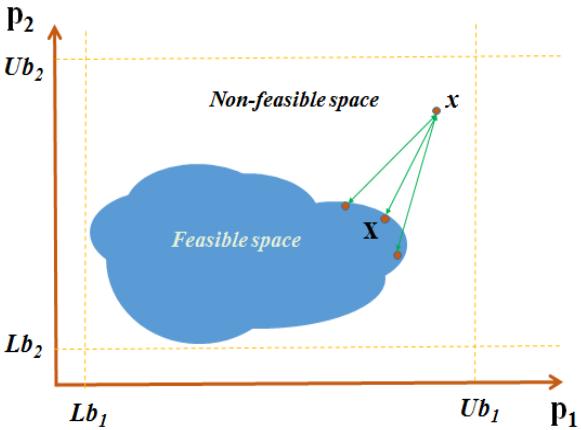


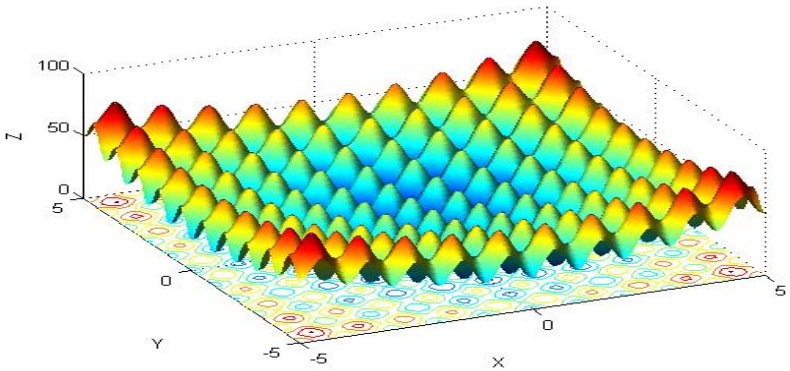


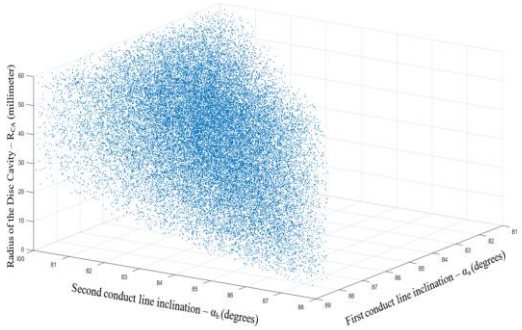
Friction Coefficient Effect

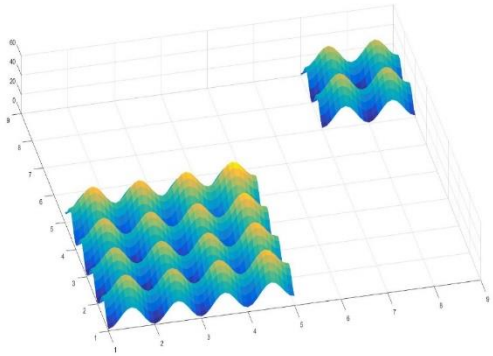


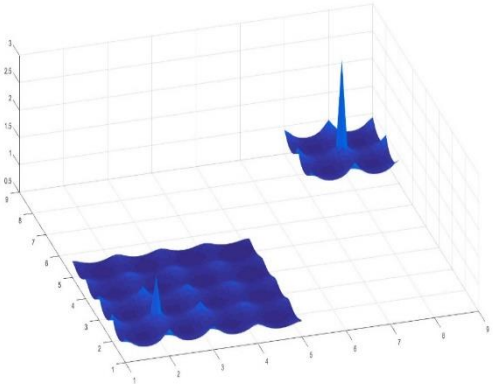
LHS-BASED ADAPTIVE PENALTY - FEASIBILITY



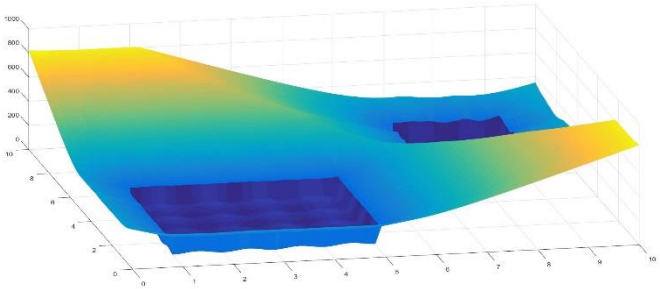






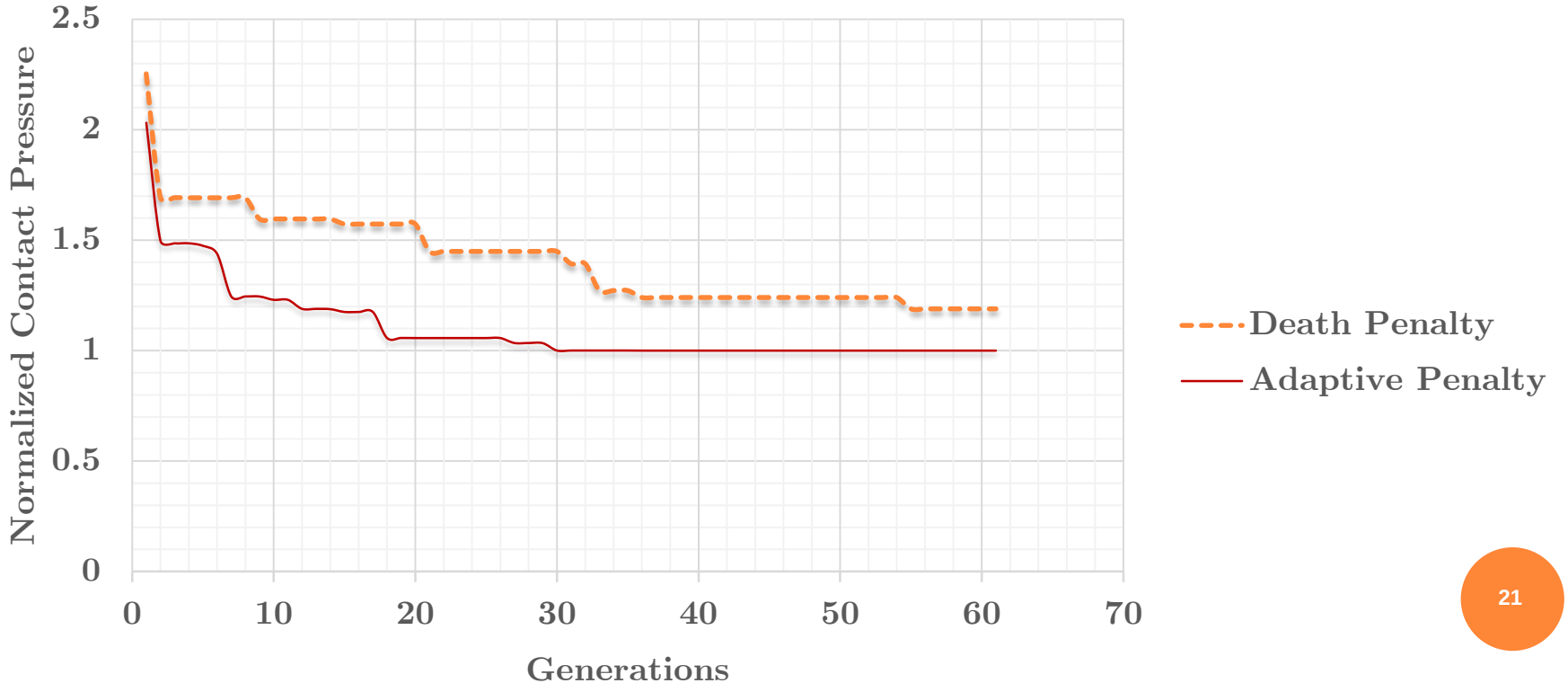


$$\phi_P(x) = \begin{cases} \phi(x) & ,if\ x\ is\ feasible. \\ C_f\left(\sum_{i=1}^{NP}\left(\frac{x_i - X_i}{Ub_i - Lb_i}\right)^2 + 1\right) & ,if\ x\ is\ not\ feasible. \end{cases}$$

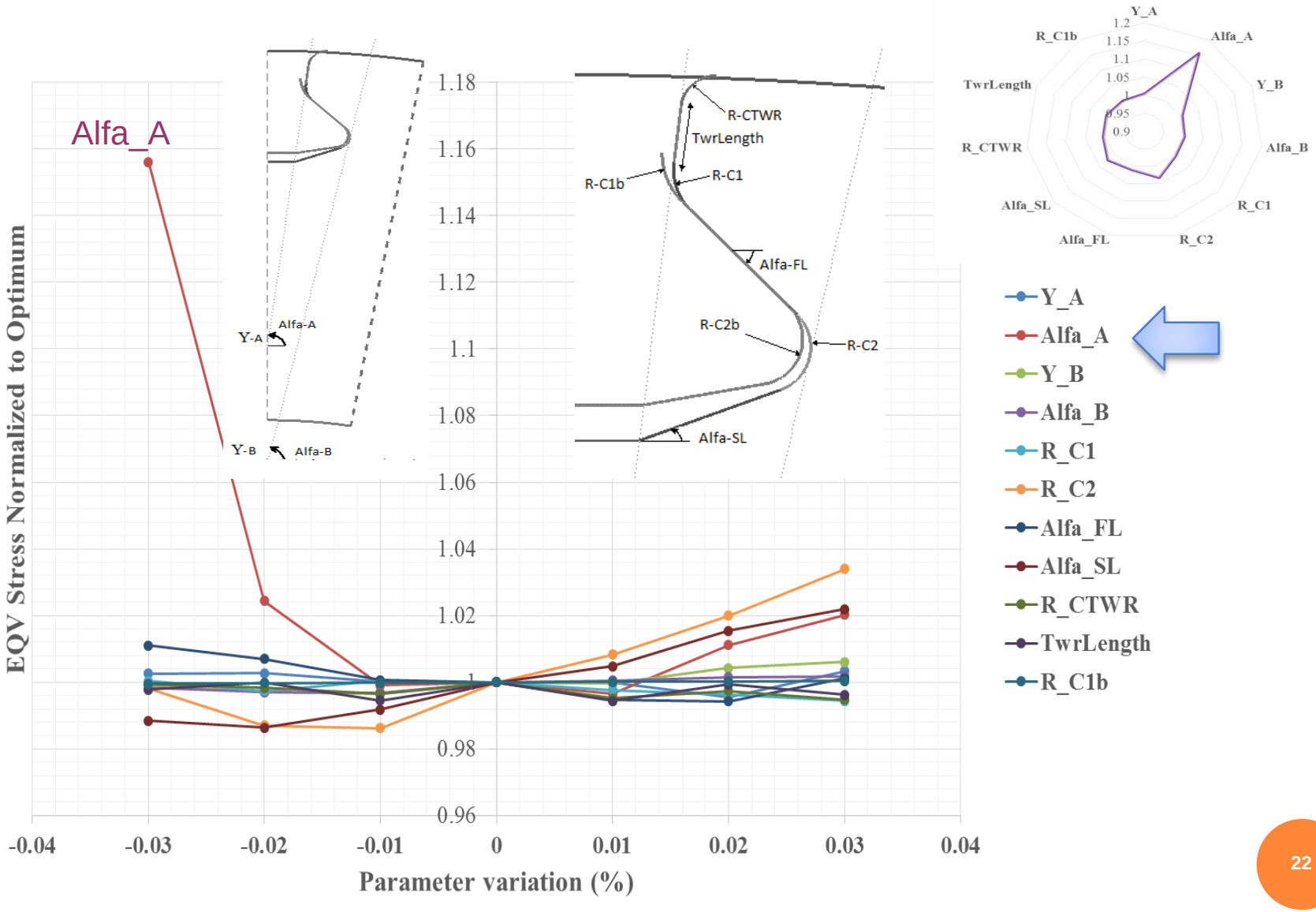


Adaptive Penalty – Efficient & Effective

$$\phi_P(x) = \begin{cases} \phi(x) & , if\ x\ is\ feasible. \\ C_f\left(\sum_{i=1}^{NP}\left(\frac{x_i - X_i}{Ub_i - Lb_i}\right)^2 + 1\right) & , if\ x\ is\ not\ feasible. \end{cases}$$



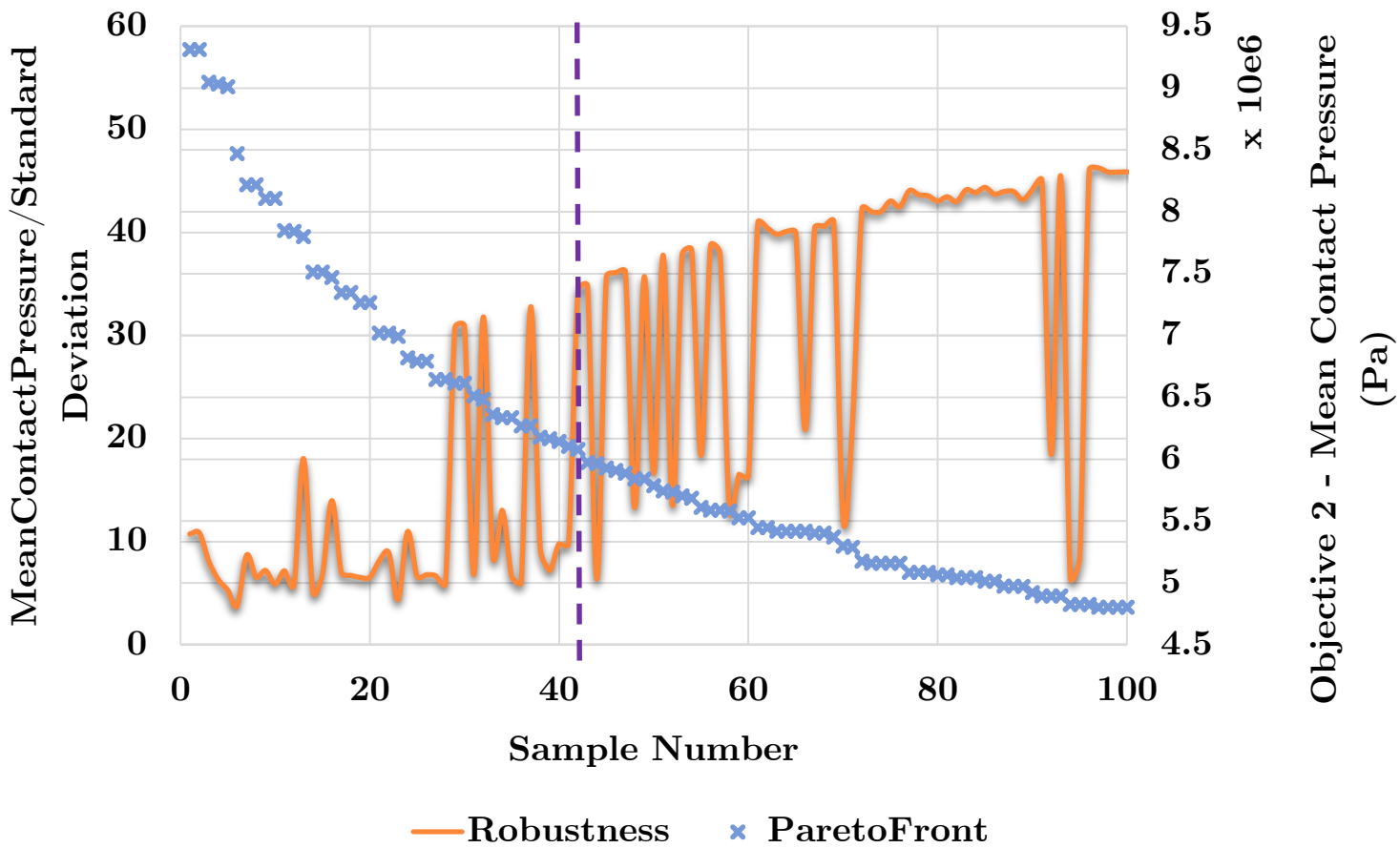
Local Sensitivity Analysis (not a good idea!)



Robustness (global Sensitivity)

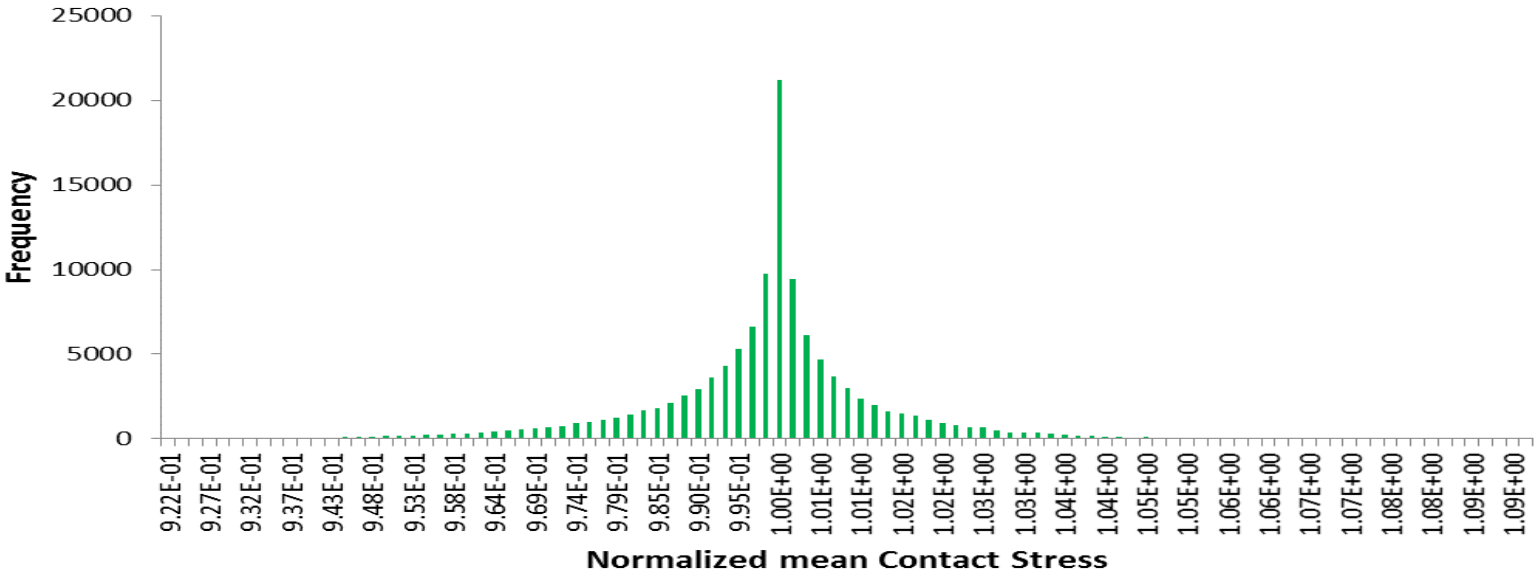
signal to noise (S/N) ratio

$$S = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(CMP_i - \mu)^2}$$



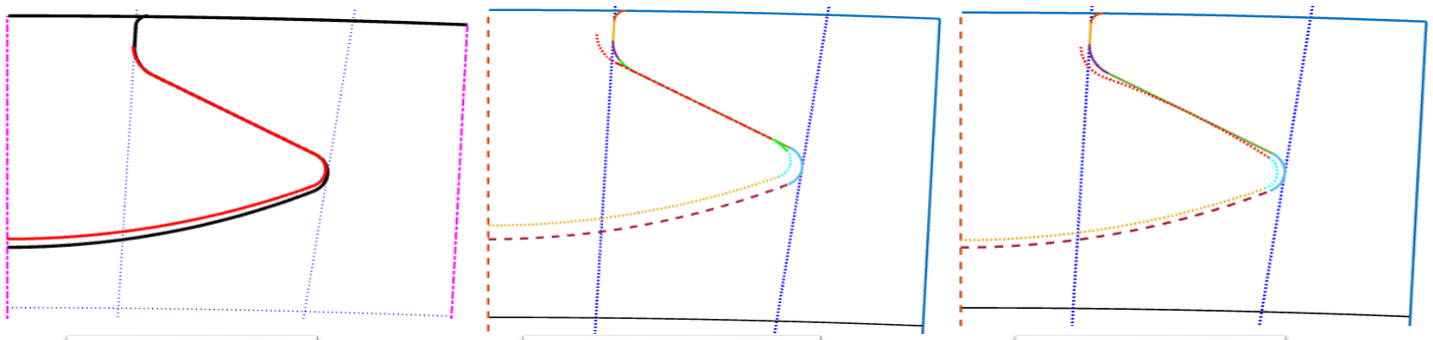
ROBUSTNESS

signal to noise (S/N) ratio

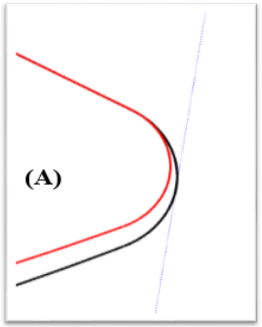


	MPS1 (normalized)	Contact Mean Pressure (Mpa)
Standard Deviation	0.026	1.7
Mean	0.583	60.46
S/N	22.42	35.56

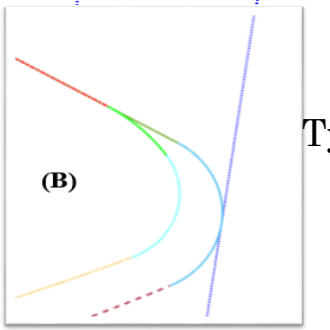
Different Contact Topologies



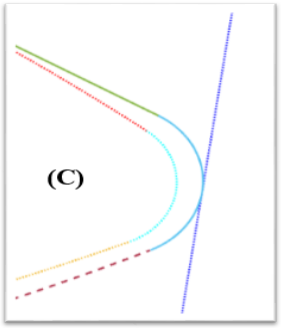
Type-I

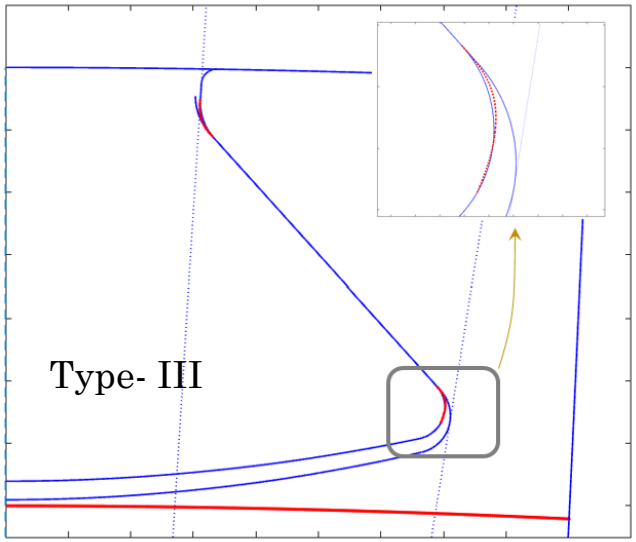


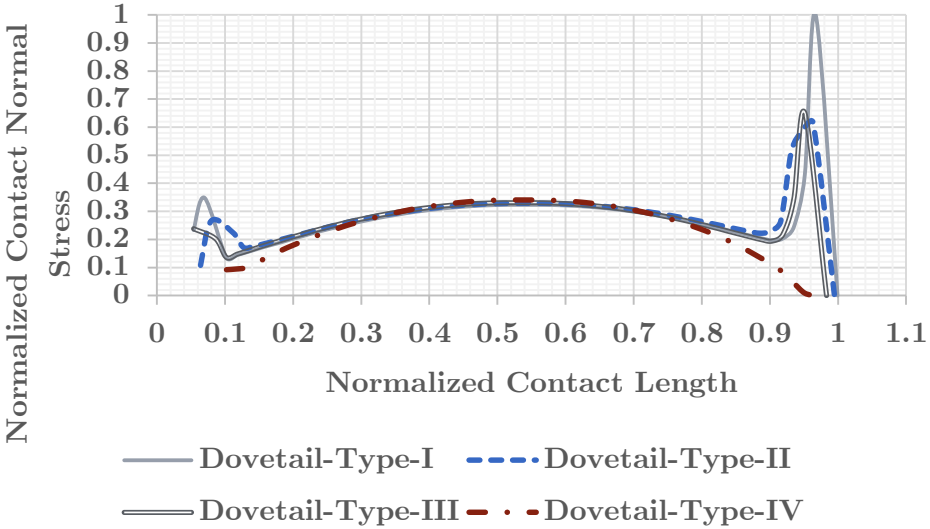
Type- II



Type- IV







Conclusion & Achievements

- *The Parametric model showed a good flexibility to provide different shapes of the attachment.*
- *The feasibility check in-house code could filter out the non feasible geometries before proceeding to the objective analyzer with a high reliability.*
- *An optimizer based on Genetic Algorithm has been developed to find an optimum geometry minimizing the objectives.*
- *To reduce the time of the optimization a Meta model was employed as an estimator prior to high fidelity but time consuming FE analysis.*
- *The proposed Adoptive Penalty method based on LHS was efficient and effective which showed faster convergence in optimization (up to 40%).*
- *The global sensitivity analysis was performed applying the Meta model.*