Tolerance Optimization of Supersonic ORC Turbine Stator

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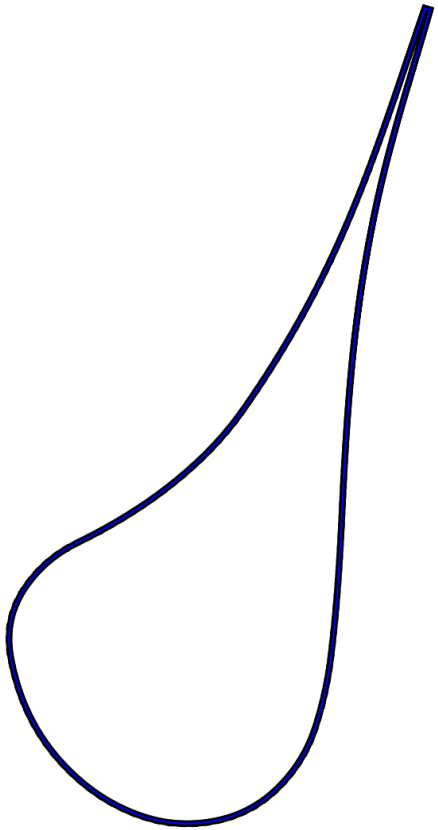
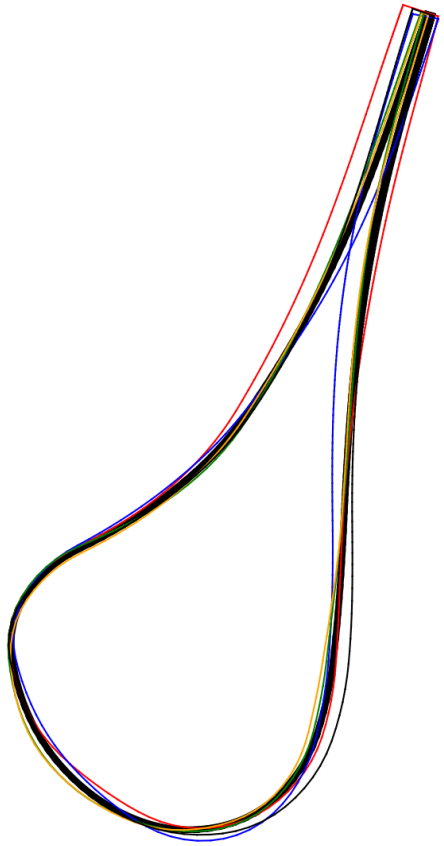
Motivation

ORC Turbine Stator: 2D profile



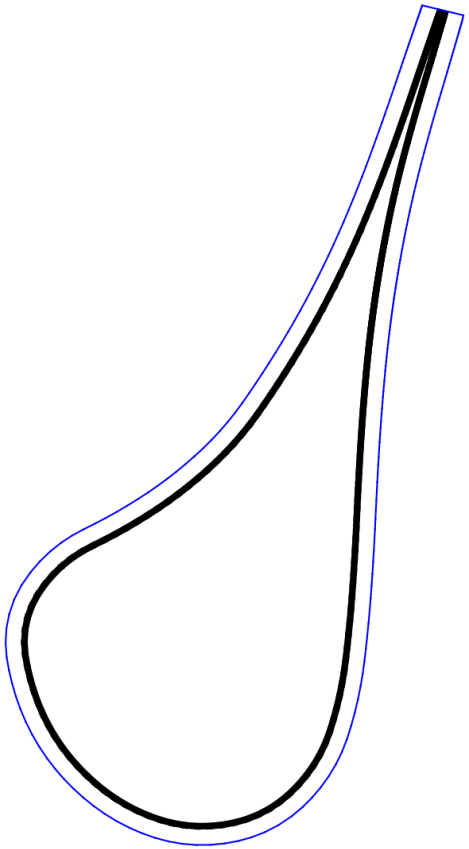
Perfect Geometry



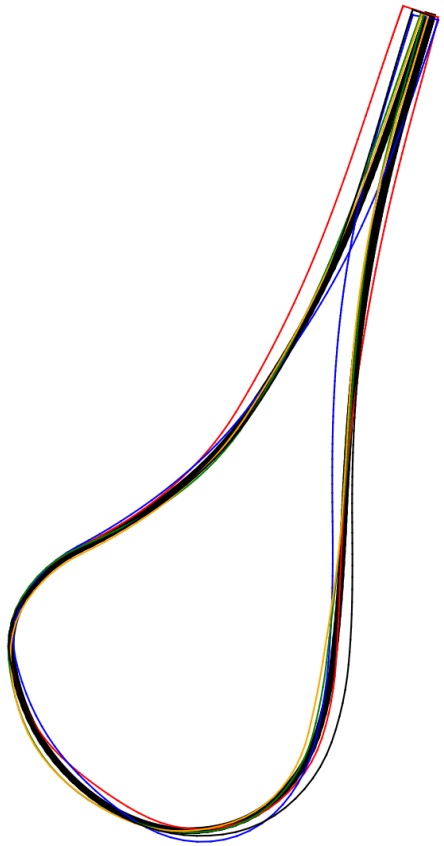
Manufactured blades

Motivation

→ **Geometric Tolerance Representation**



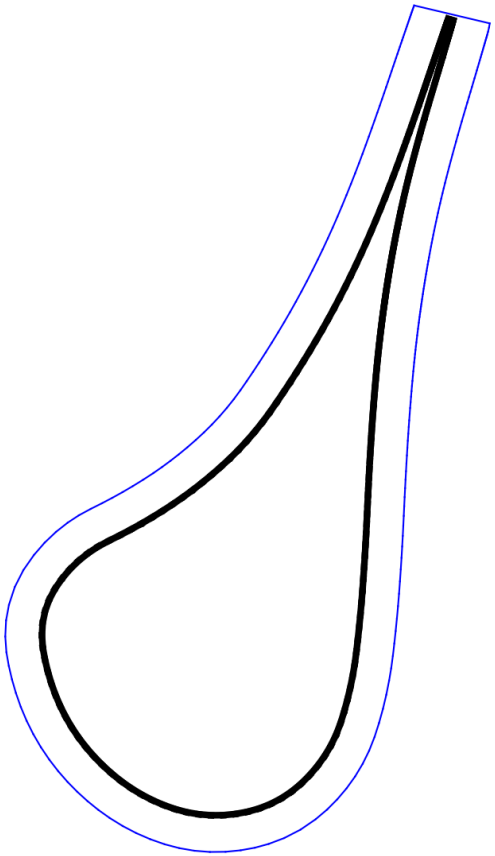
Geometric Tolerance



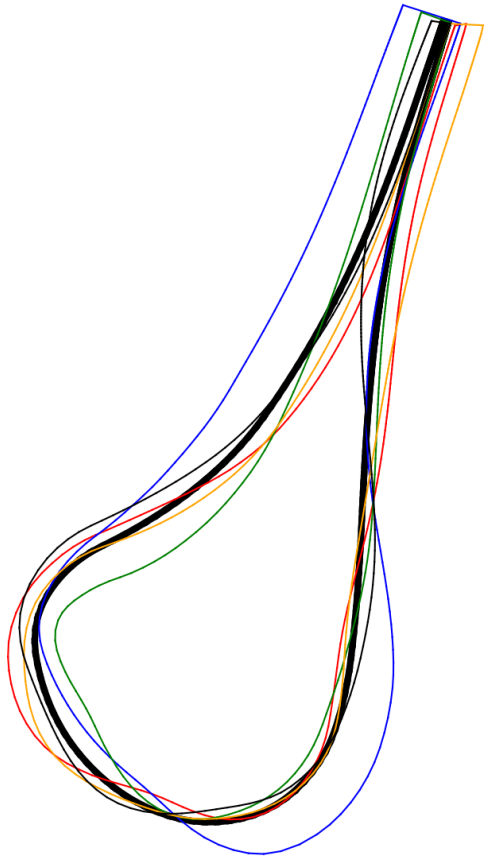
Manufactured blades

Motivation

→ **Geometric Tolerance Representation**: Larger



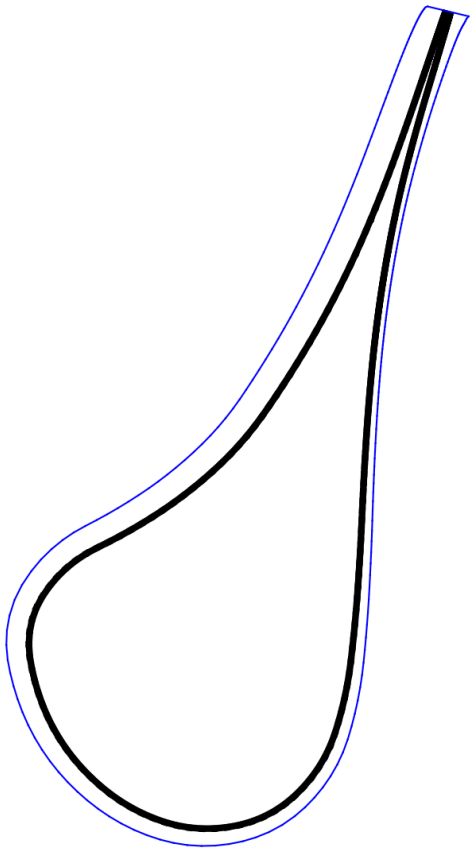
Geometric Tolerance



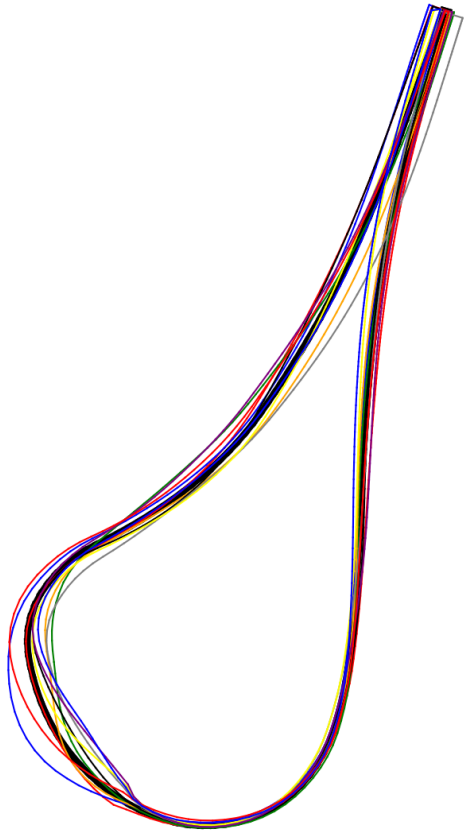
Manufactured blades

Motivation

→ **Geometric Tolerance Representation**: Not Uniform



Geometric Tolerance



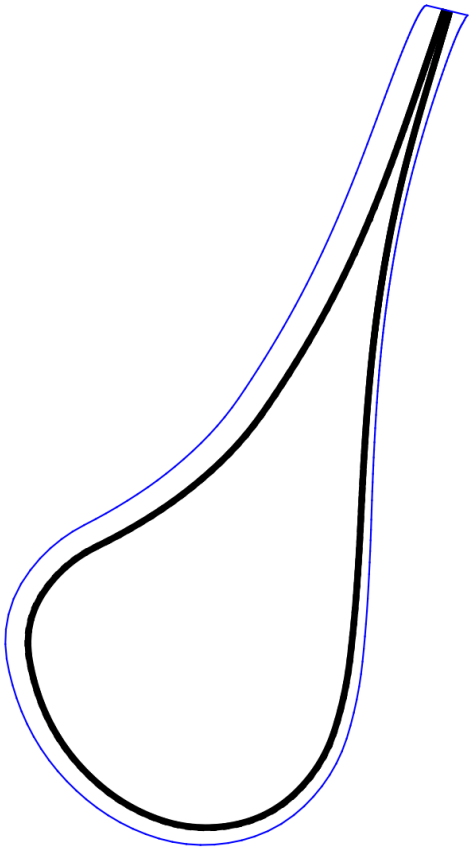
Manufactured blades

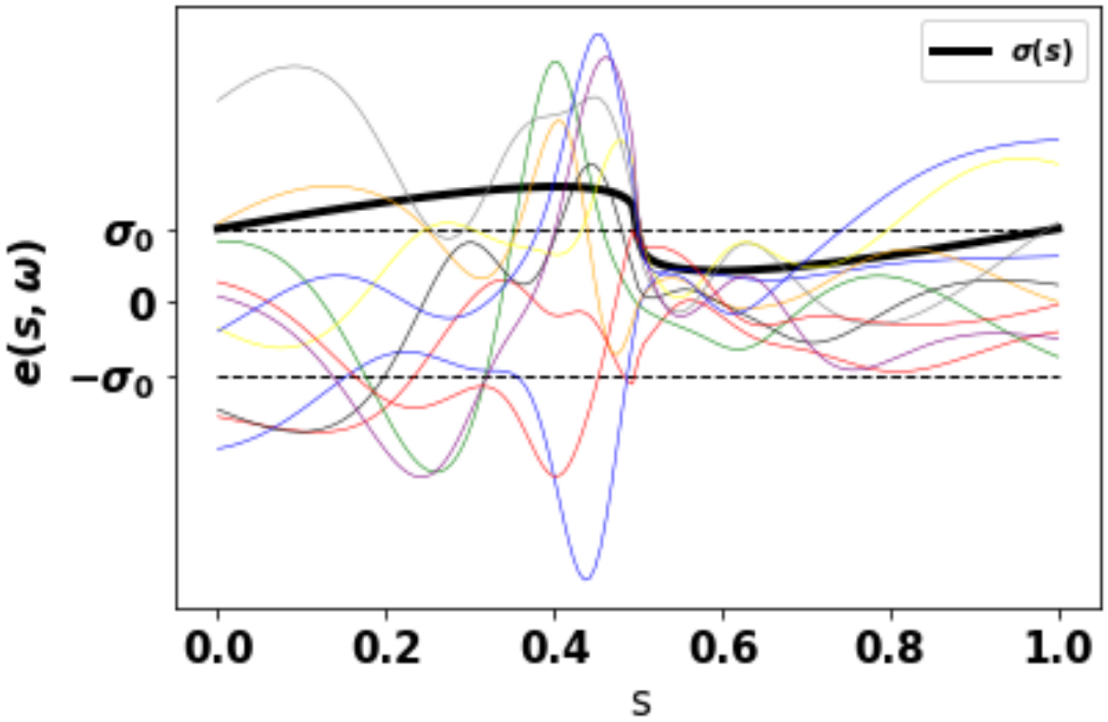
Motivation: Objective

Min **F**(**x**)

x represents 1D tolerance distribution

F(**x**)$=q_{\xi}^{80}\left[f_{\xi}(\mathbf{x})\right] \rightarrow$ **Robust Optimization**





1D "Tolerance(**x**)"

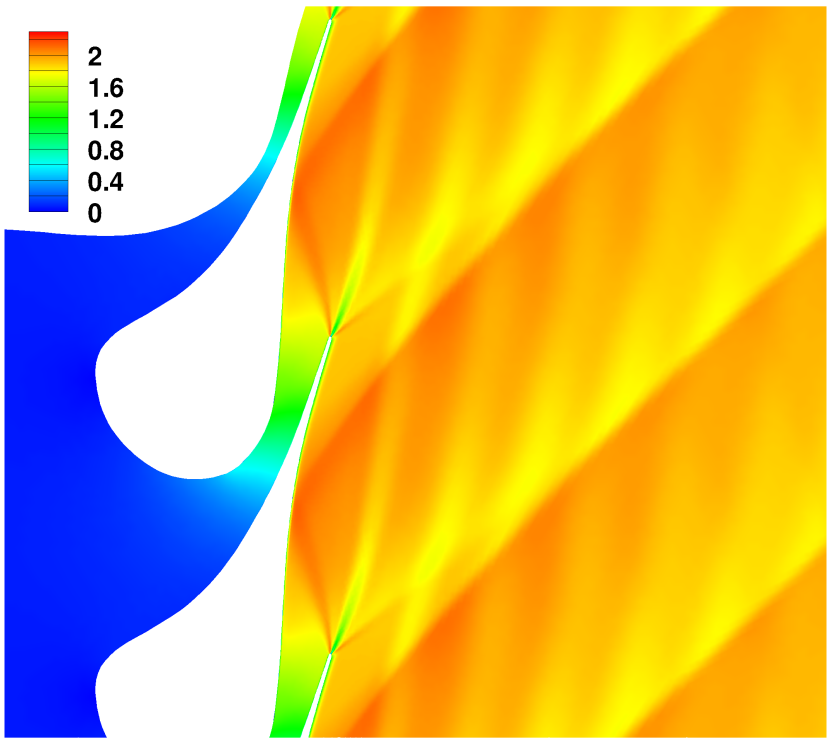
Contents

CFD Model

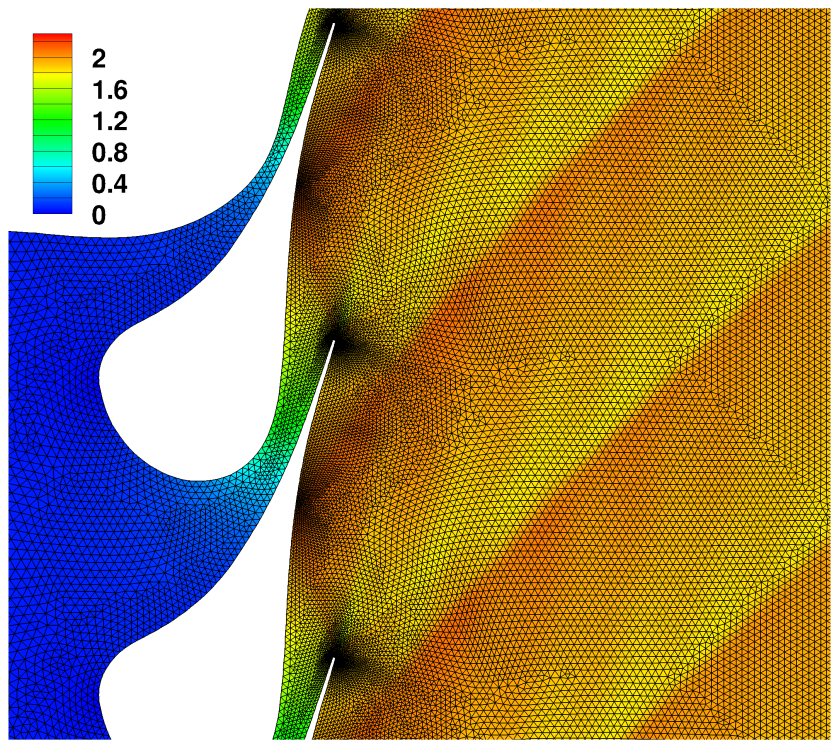
NICFD: SU2

- Euler 2^{nd} order ARS, Van Albada limiter, NRBC
- Fluid MDM (dense gas) polytropic Peng-Robinson
- Loss Coefficient: $f = \Delta P = \sqrt{\frac{1}{N}\sum_i (P_i - \bar{P})^2}$

Supersonic ORC Turbine Stator



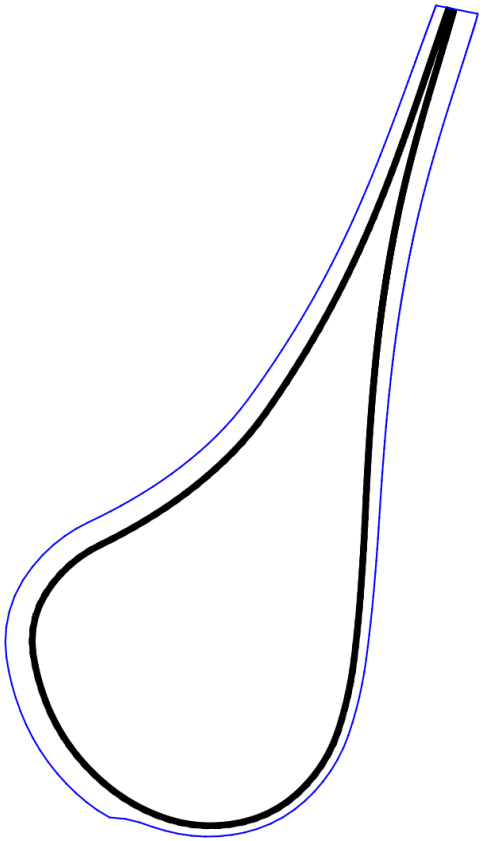
Inviscid: Mesh 16k

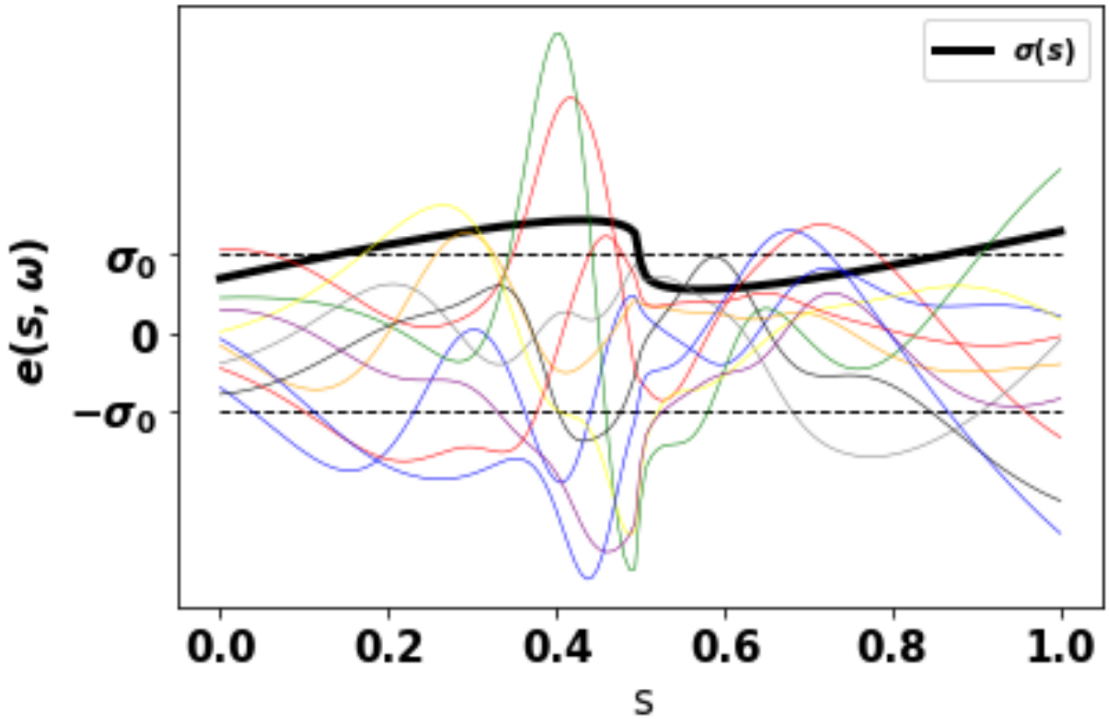


Geometric Tolerance Modeling

e(s,ω): Gaussian Random Field 1D

$\rightarrow \sigma(s)$, $\rho(s,t)$





"Tolerance(**x**)": Standard Deviation $\sigma_{\mathbf{x}}(s)$

Geometric Tolerance Modeling

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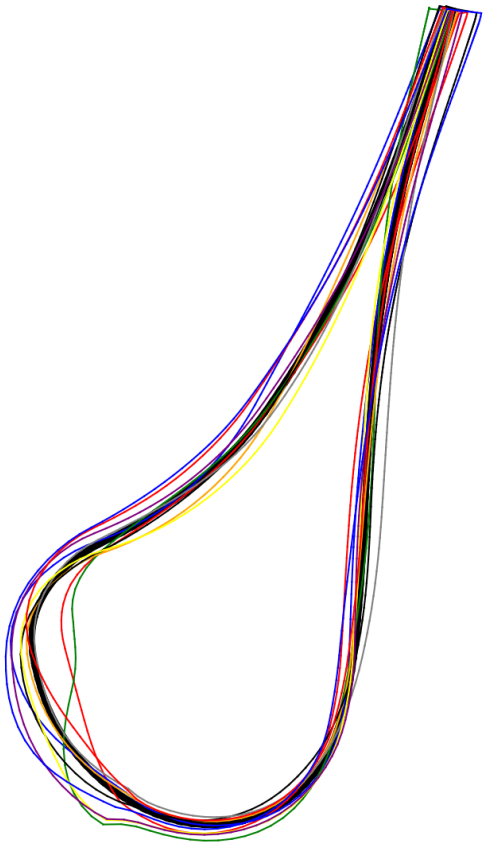
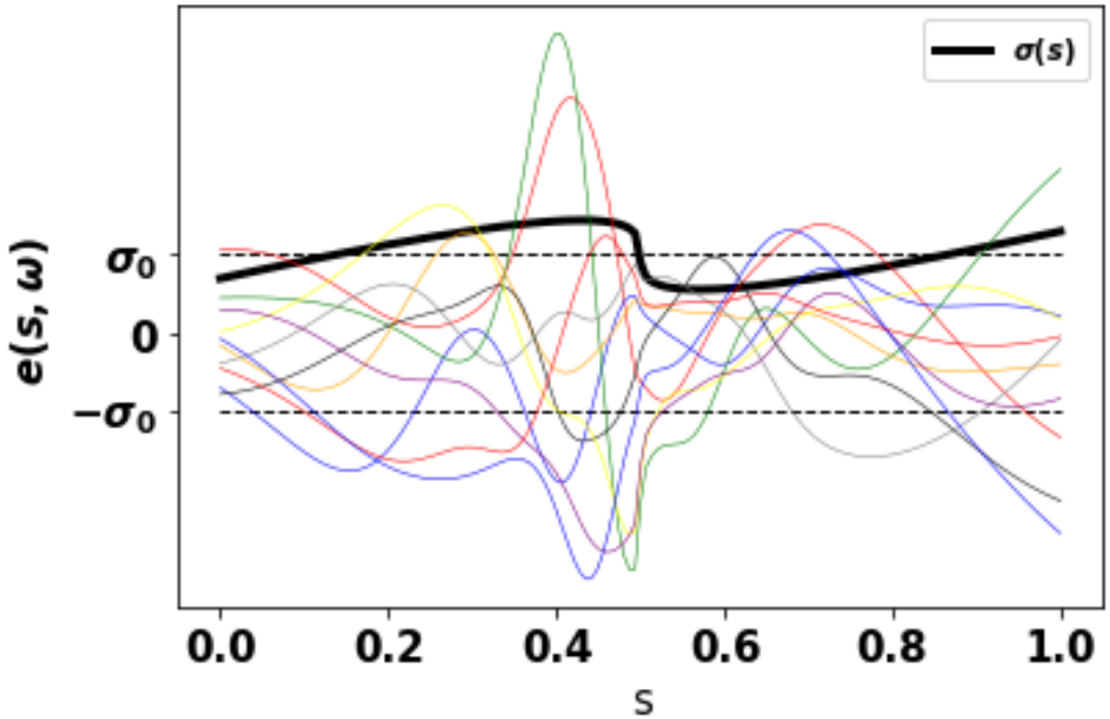
$\rightarrow \sigma(s)$, $\rho(s,t)$





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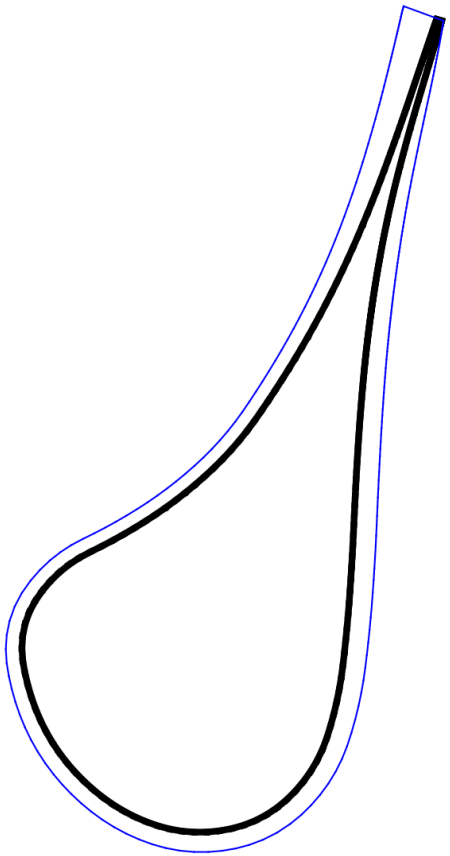

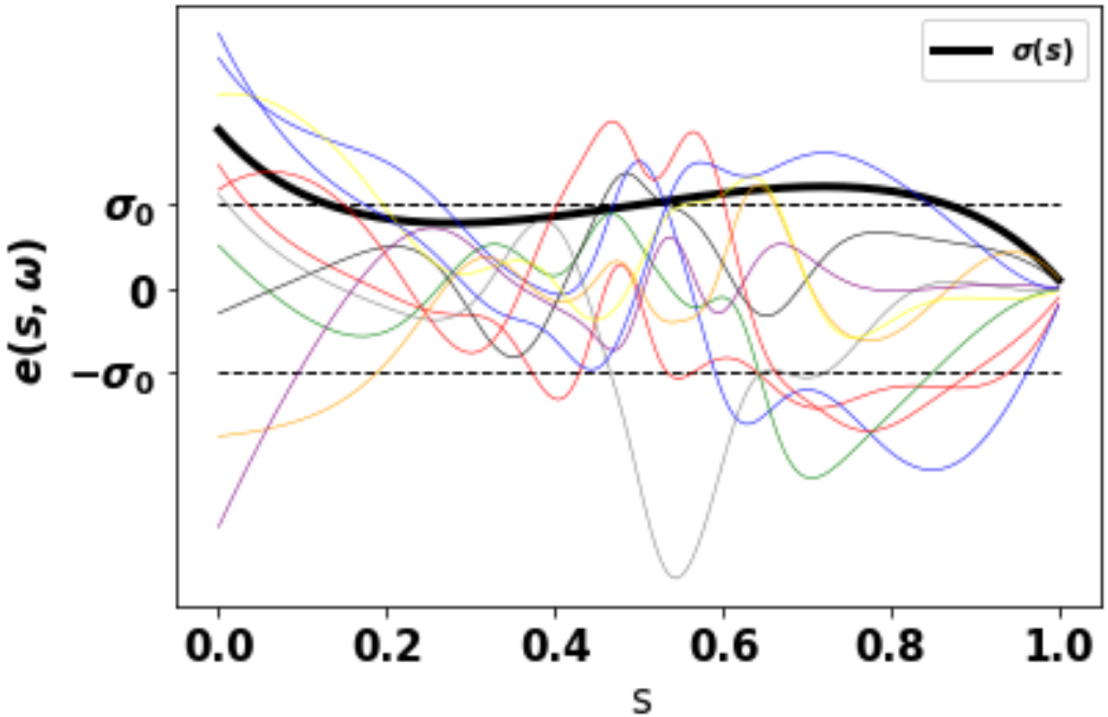

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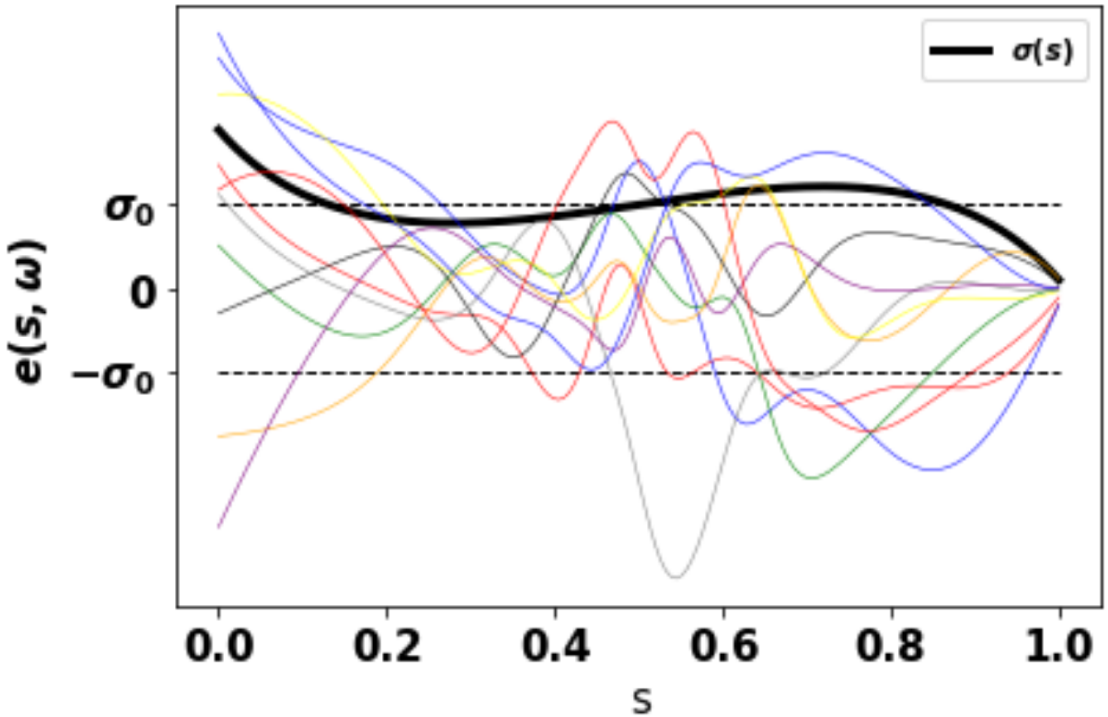
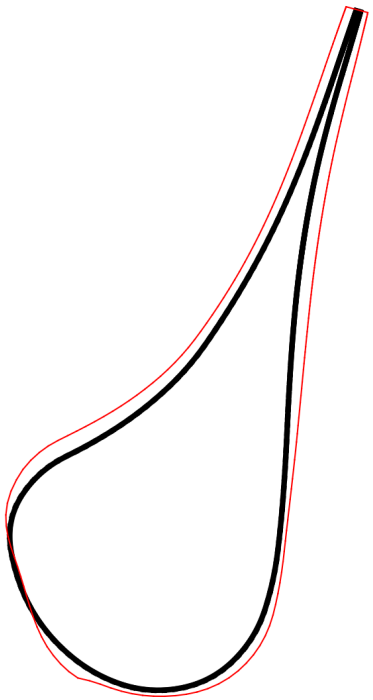


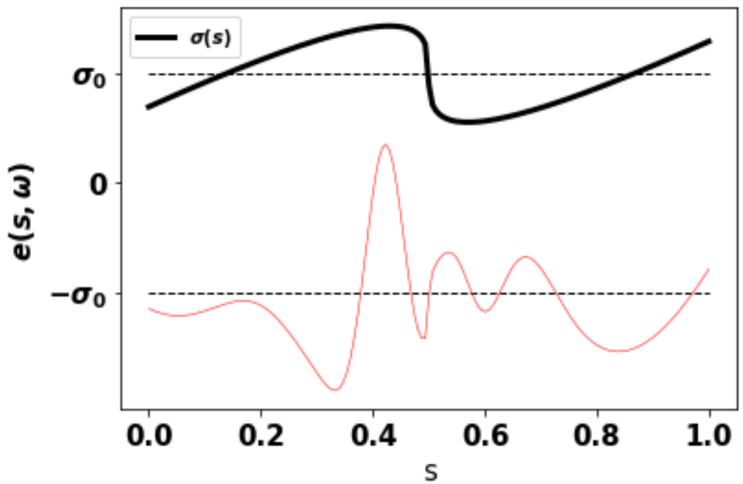
"Tolerance(**x**)": Standard Deviation $\sigma_{\mathbf{x}}(s)$

Stochastic Model

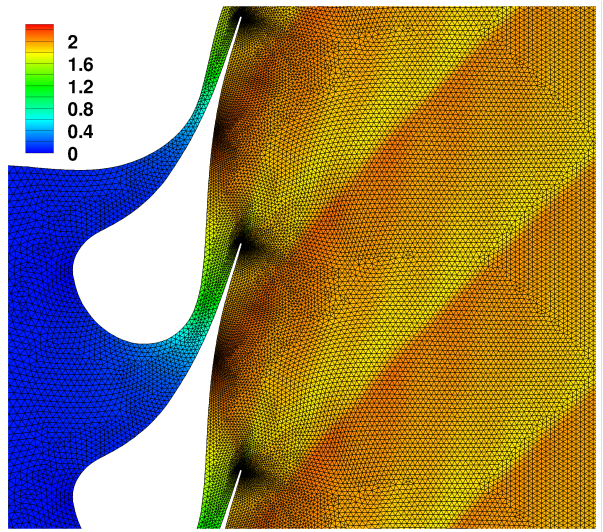
$\mathbf{x} \rightarrow \Delta P(\mathbf{x})$

$\Delta P(\mathbf{x})$: Random Variable
Min q^{80} $[\Delta P(\mathbf{x})]$



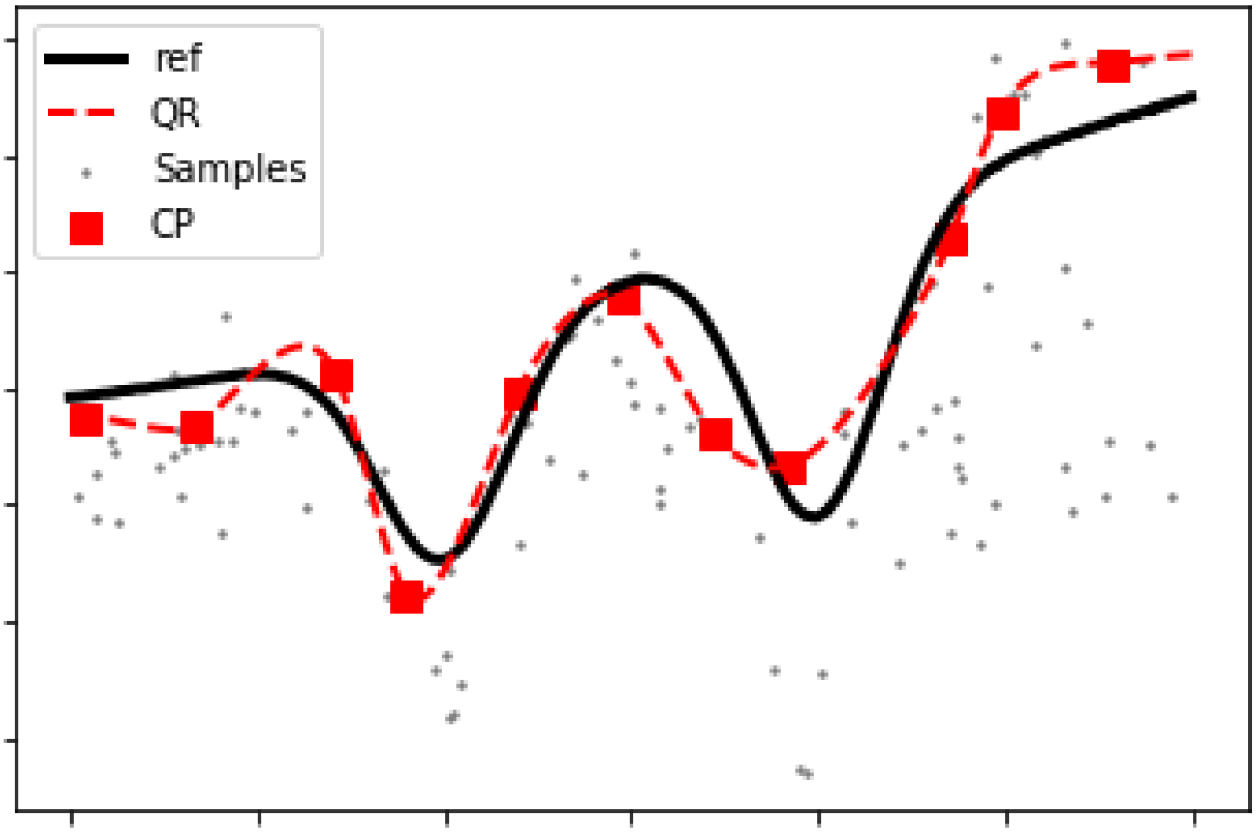


$\sigma_{\mathbf{x}}(s)$



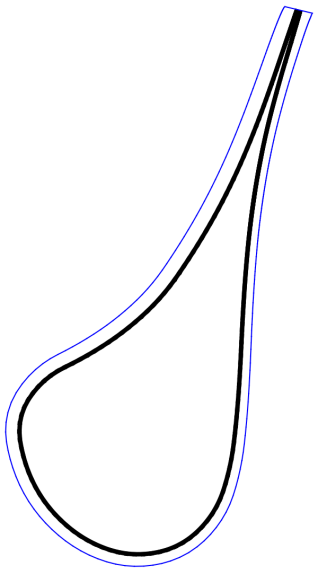
CFD: $\Delta P(\mathbf{x})$

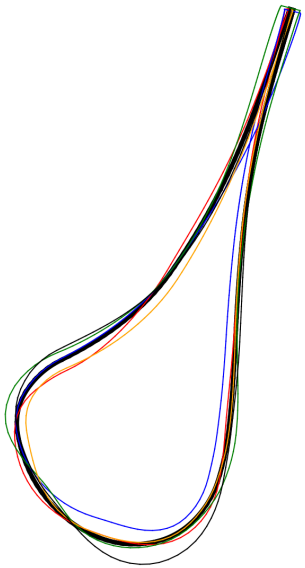
Robust Optimization Method: Quantile Regression

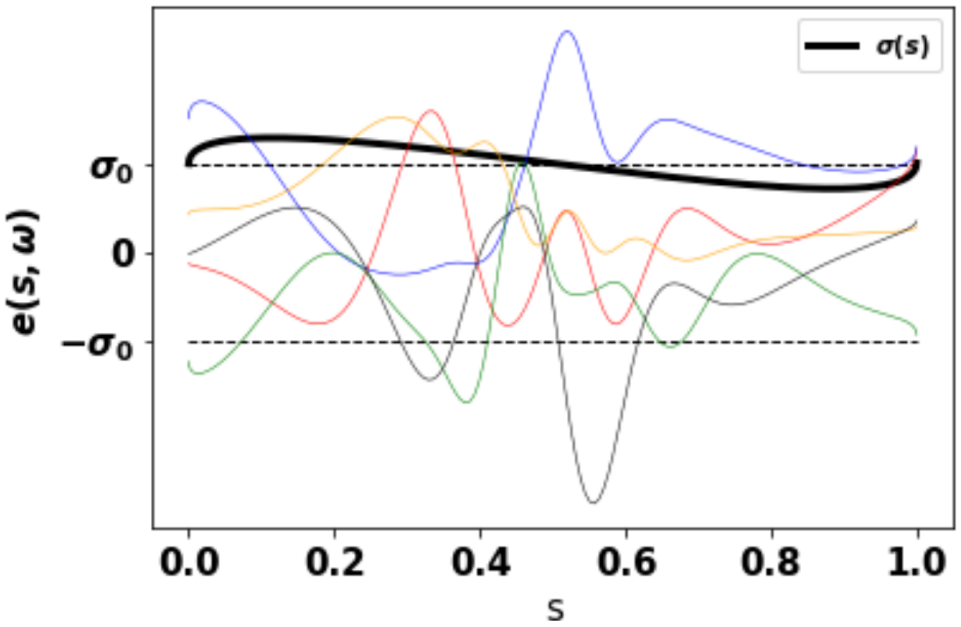


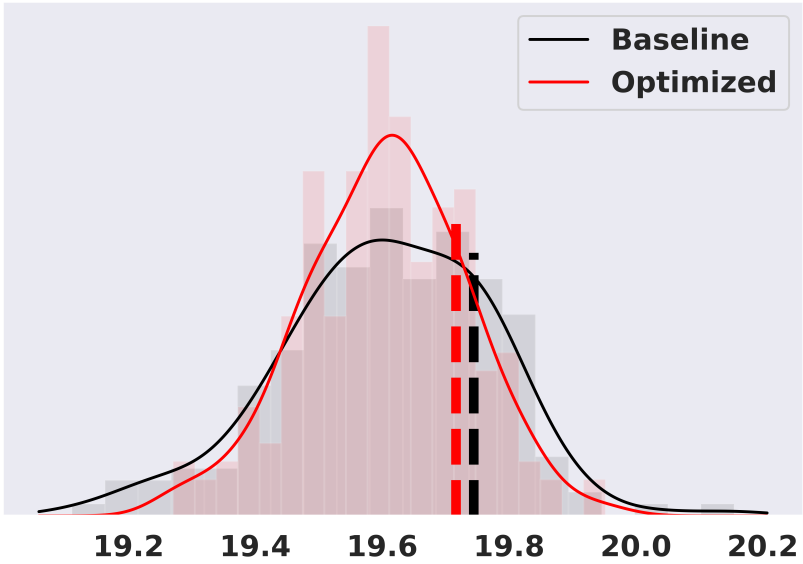
- n_0 CFD runs
- Approximate $q^{80}(\mathbf{x})$
- Find $\mathbf{x}^* = \text{Argmin } q^{80}(\mathbf{x})$
- Evaluate $\Delta P(\mathbf{x}^*)$

Results





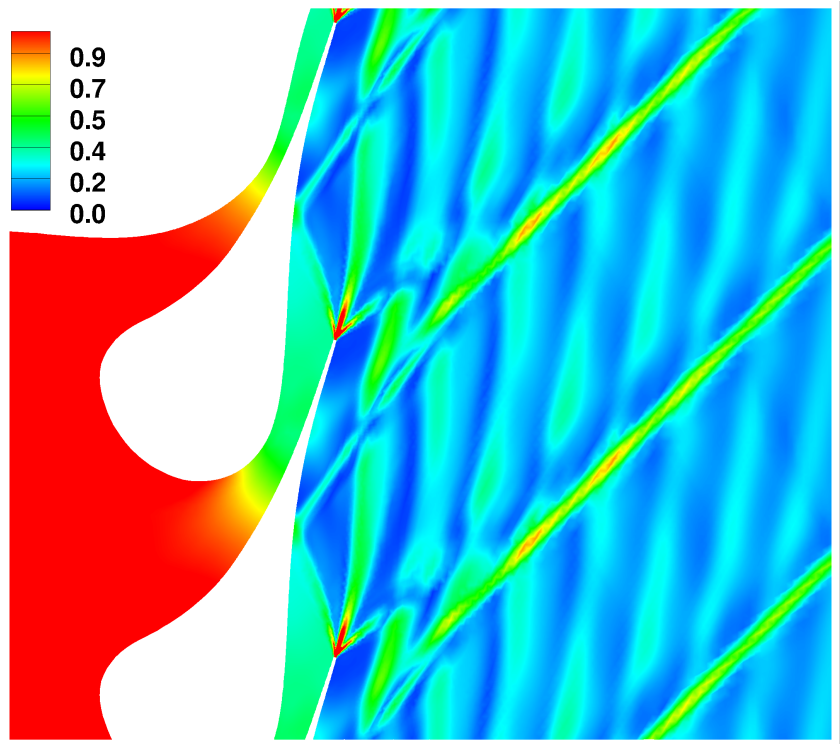

σ(s)
σ0
0
−σ0
e(s, ω)
0.0
0.2
0.4
0.6
0.8
1.0
s


Baseline
Optimized
19.2
19.4
19.6
19.8
20.0
20.2

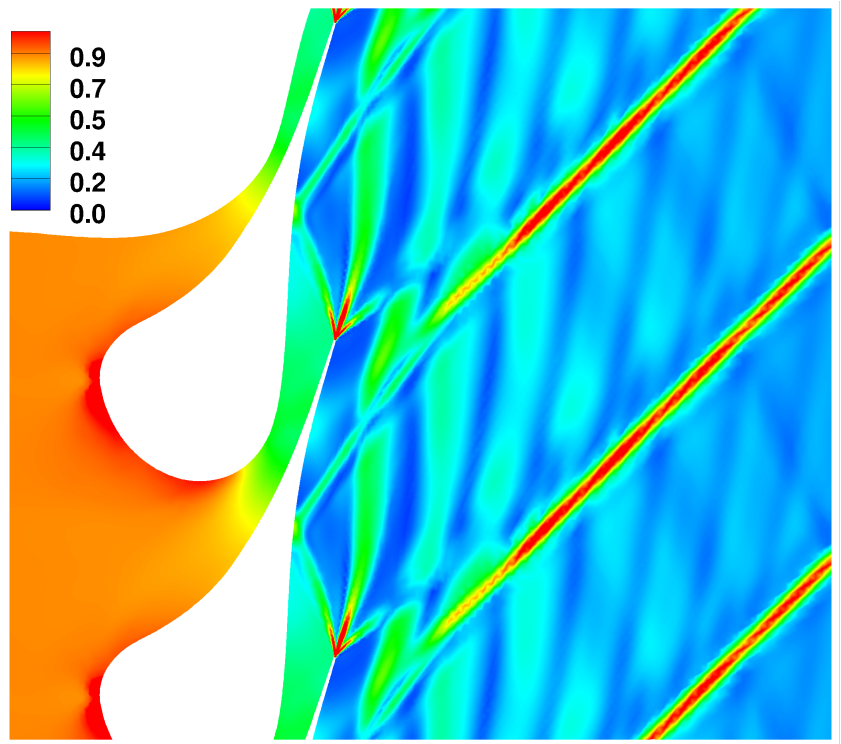
Results

Mach Contours: $\frac{\sigma}{\mu}$

$\rightarrow$ Normalized standard deviation



Baseline



Optimized

Conclusion

Preliminary Study: Tolerance (Robust) Optimization

- 3 design variables
- ~ 600 CFD runs: $n_0 = 200,\ n_{it} = 32$
- Quantile Regression (Large Stochastic Dimension)
- Inviscid Model

Limitations

- Low design dimension (< 10)
- Gaussian Random Field: realistic?

Future Work

- High Fidelity CFD Models
- Design Space Parametrization
- Tolerance Modeling (PCA,...)
- 3D profiles