RANS Investigation of Blowing and Suction for Turbulent Flow Control on a Wing Section

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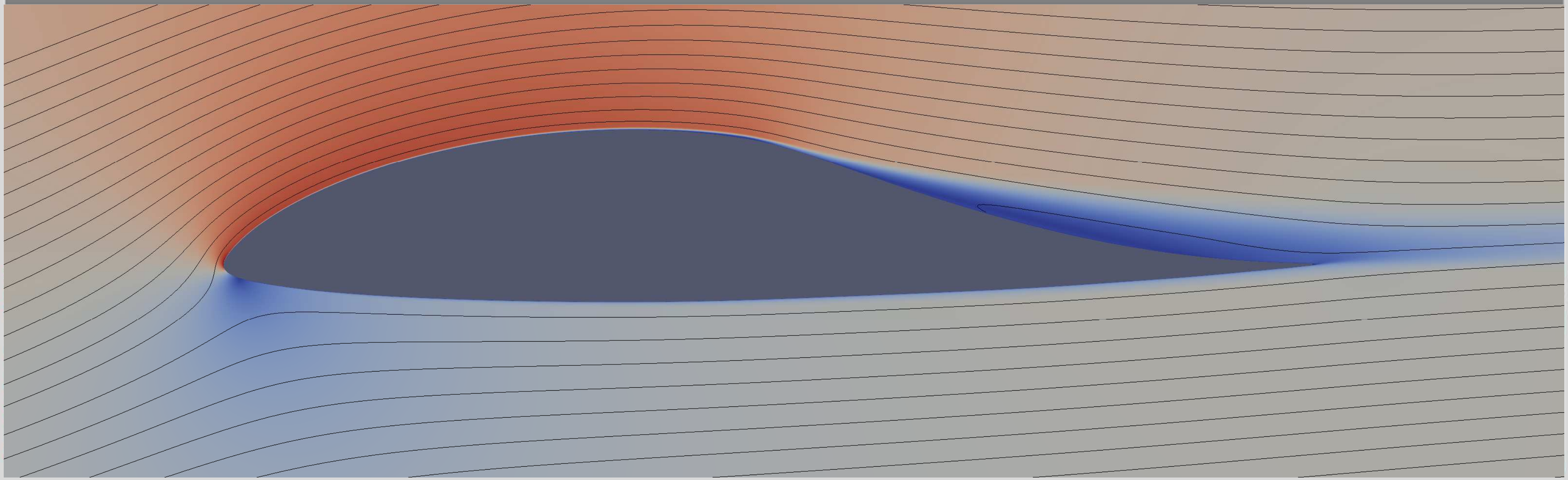


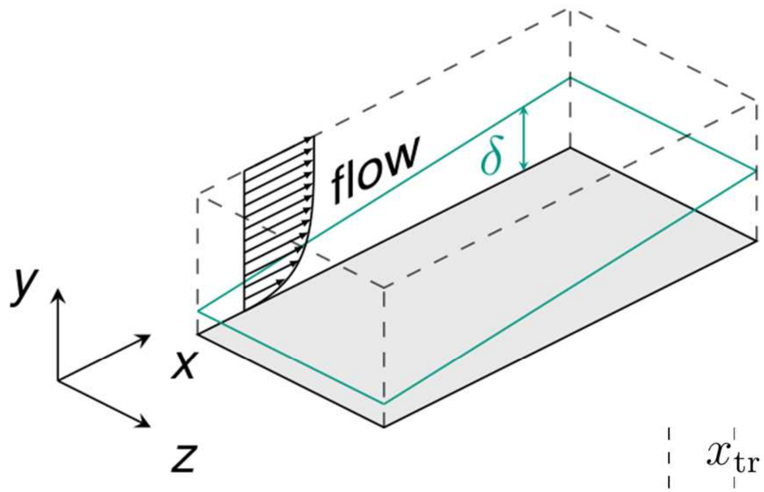
Boundary Layer Control Scheme

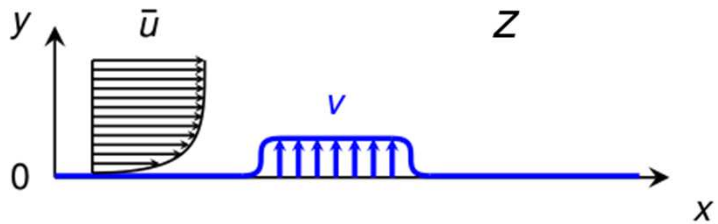
Uniform Suction/Blowing

- Active Control Scheme
- Low Blowing Intensity (0.025-2% of U_∞)
- Flat plat: 80% drag reduction

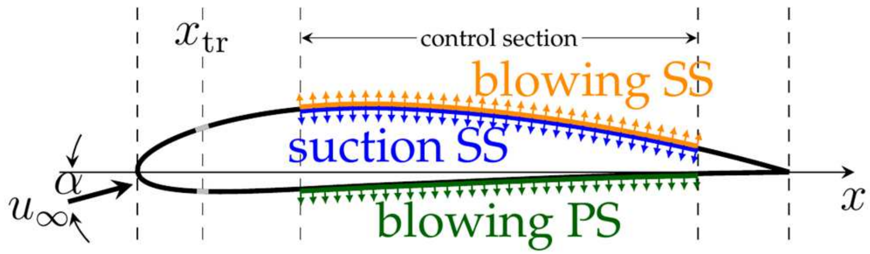
Developing Boundary Layer

- Blowing → $\delta \uparrow$, $\tau \downarrow$
- Suction → $\delta \downarrow$, $\tau \uparrow$





[A. Stroh, Diss. 2015]



Motivation / Objective

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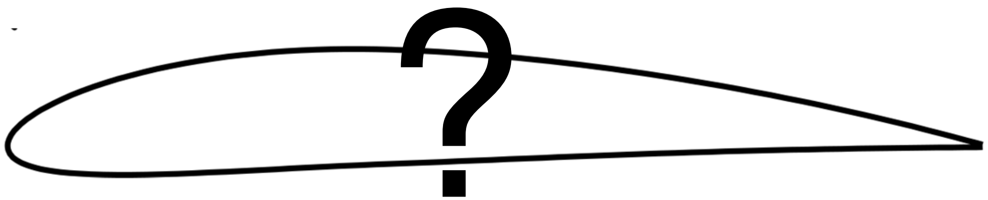
Airfoil requirements

- Lift
- Efficiency
- Momentum
- Stall properties
- Control surfaces
- Re
- $Mach$
- …

Means

- Shape
- Flaps, etc.
- **Boundary Layer Control (BLC)**



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Methodology

General

- RANS, low-Re, incompressible
- OpenFOAM → SIMPLE FOAM
- $k\omega$-SST

Fully turbulent flow

Laminar Flow + Tripping

$x_{tr} = 0.1c$ → Source for k

$k\omega$-SSTLM

- Transitional model
- All transition modes applicable for airfoils
- Slow/No convergence

$k\omega$-SST $k = 0,\ x \leq x_{tr}$

- Same effect as LM-model
- Fast convergence
- No natural transition
- Caution: Laminar separation bubble

Methodology - Mesh

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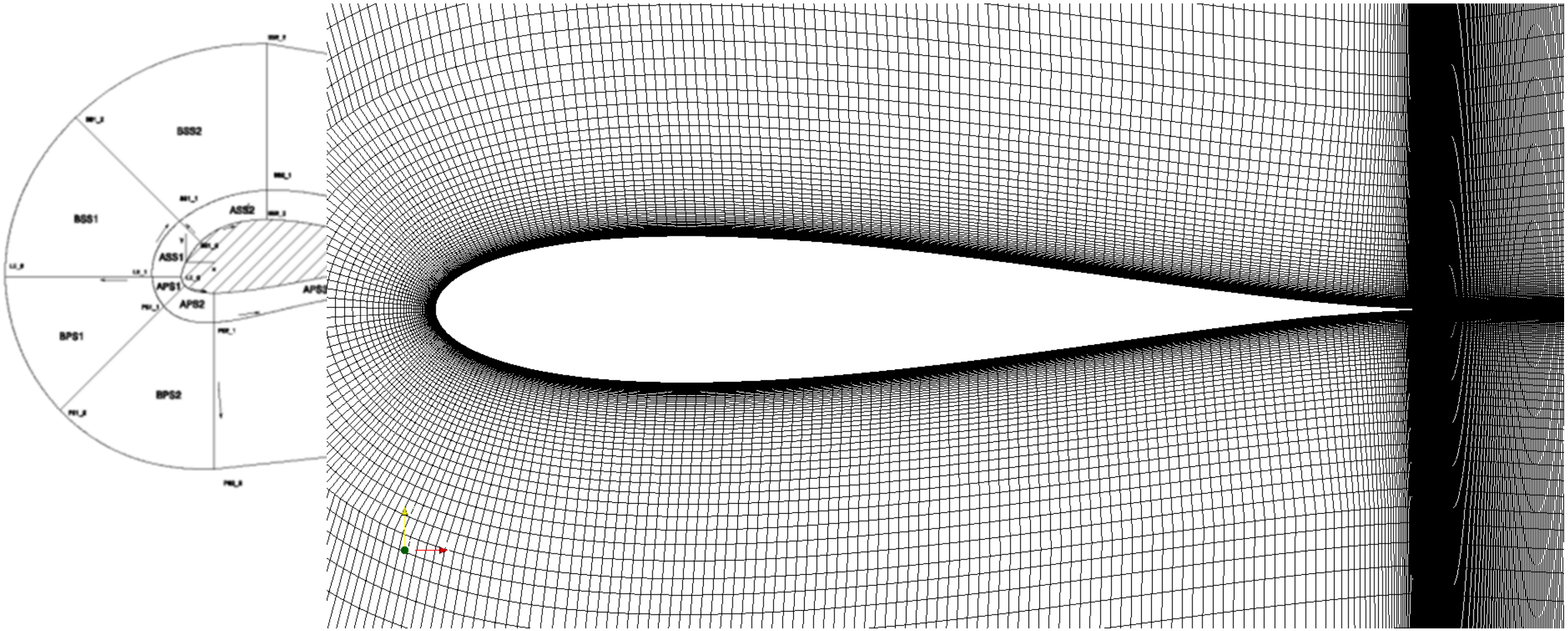
- Different Airfoils (7)
- Different Re

} $\approx$40 Meshes

→ Automated mesh generation

Structured meshes (blockmesh)

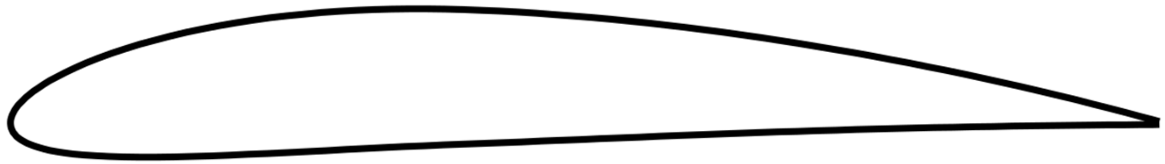


Validation

- Mesh convergence study
- XFOIL
- Experimental data:
  - ClarkY (Fukagata Lab, Keio University)

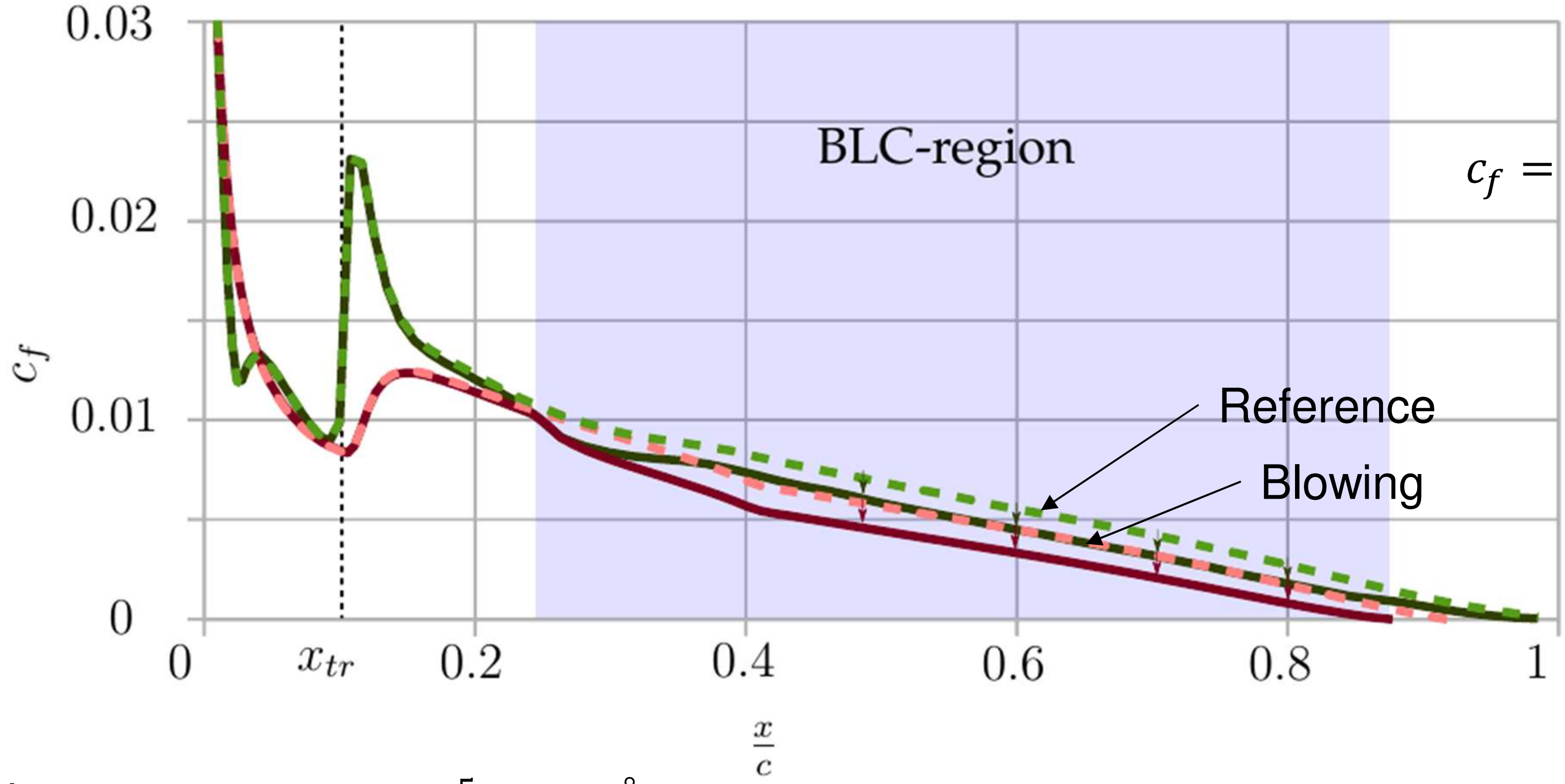
  - Naca23012 (IAG, University Stuttgart)

- DNS/LES data:
  - Naca4412 (Linné Flow Centre, KTH)



Validation – DNS/LES data

	c_l	c_d	E	Δ to reference
→ LES (KTH)	0,842	0,0202	41,7	-6,2%
RANS	0,829	0,0204	40,6	-6,6%

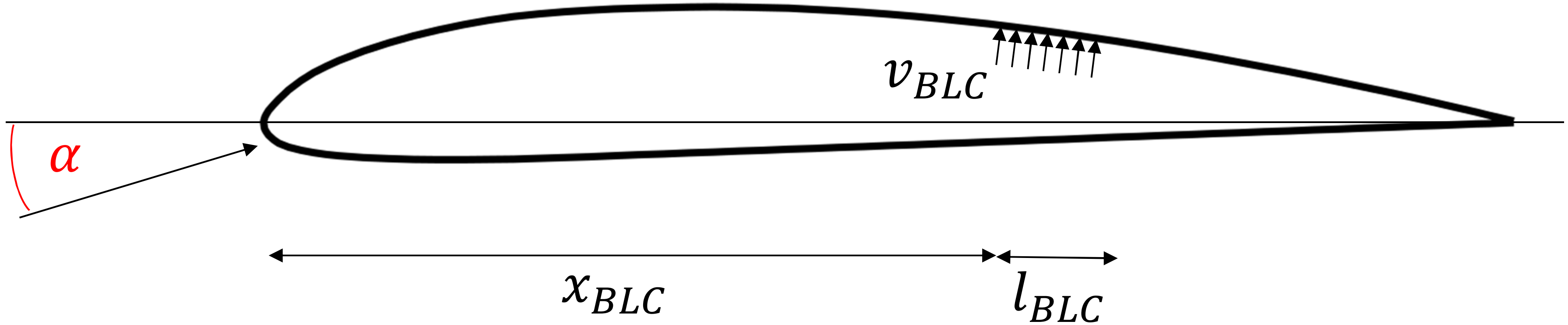


$$c_f = \frac{\tau}{\frac{1}{2}\rho U_\infty}$$

Naca4412, $Re = 2 \cdot 10^5$, $\alpha = 5^\circ$, $v_{BLC} = 0.1\% U_\infty$

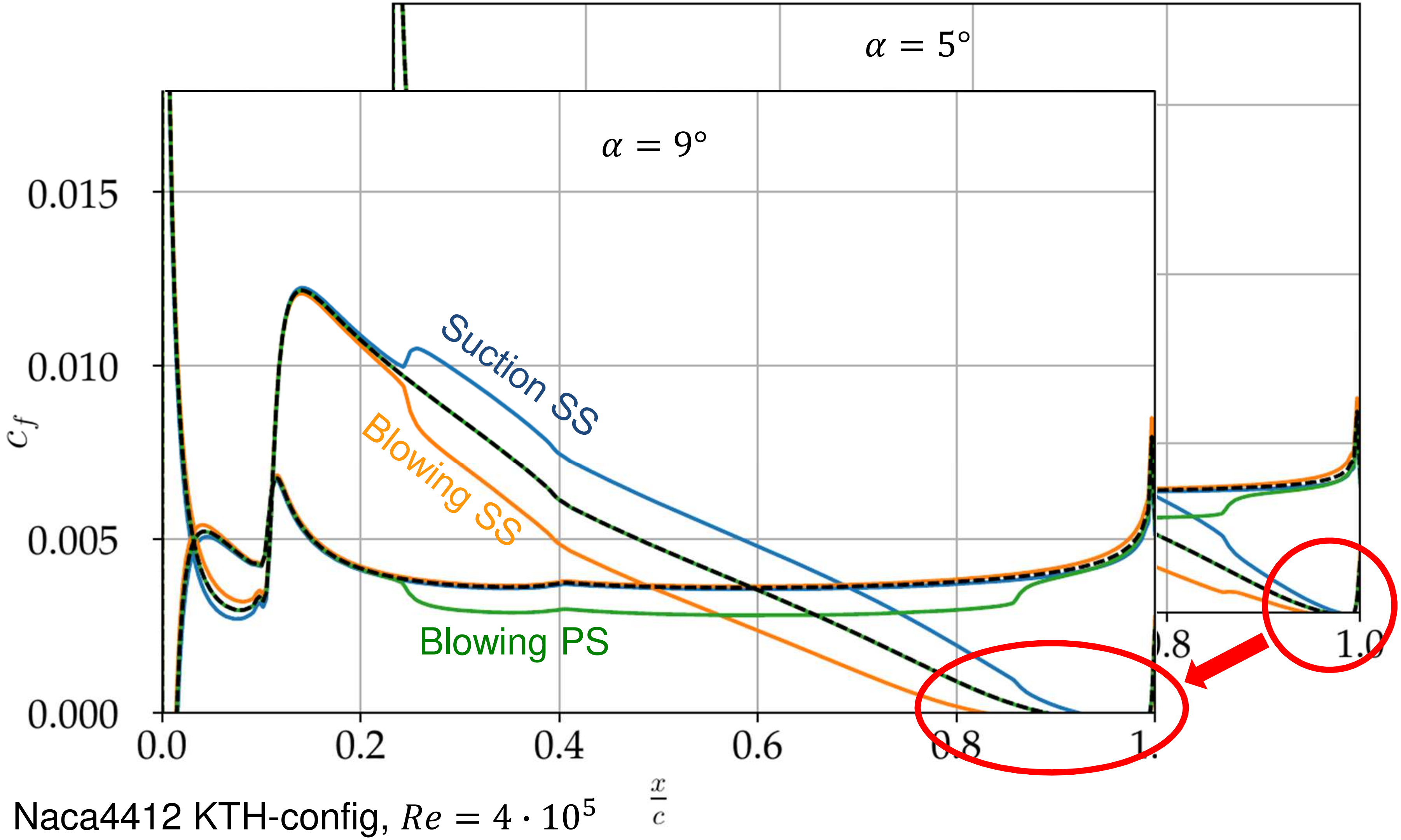
Aspects of Results

$$Re = \frac{U_\infty c}{\upsilon}$$



Using BLC and Geometry Design complementary

Wall shear stress c_f: α-Dependency



Naca4412 KTH-config, $Re = 4 \cdot 10^5$

Polar: α - Dependency

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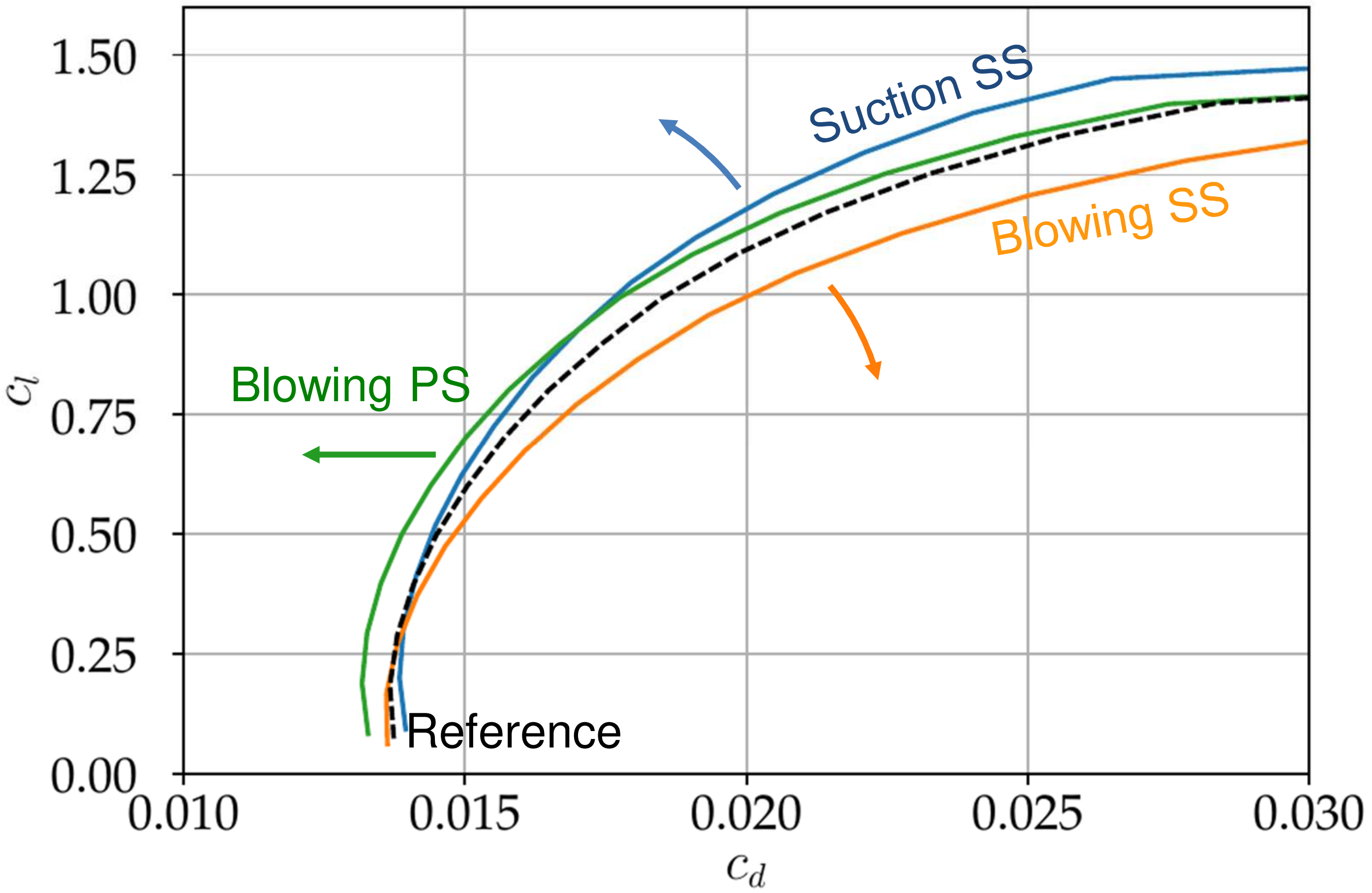


$$c_l = \frac{F_L}{\frac{1}{2}\rho U_\infty^2 A}$$

$$c_d = \frac{F_D}{\frac{1}{2}\rho U_\infty^2 A}$$

Naca4412 KTH-config, $Re = 4 \cdot 10^5$

Re-Dependency

Naca4412 KTH-config, $\alpha = 5°$

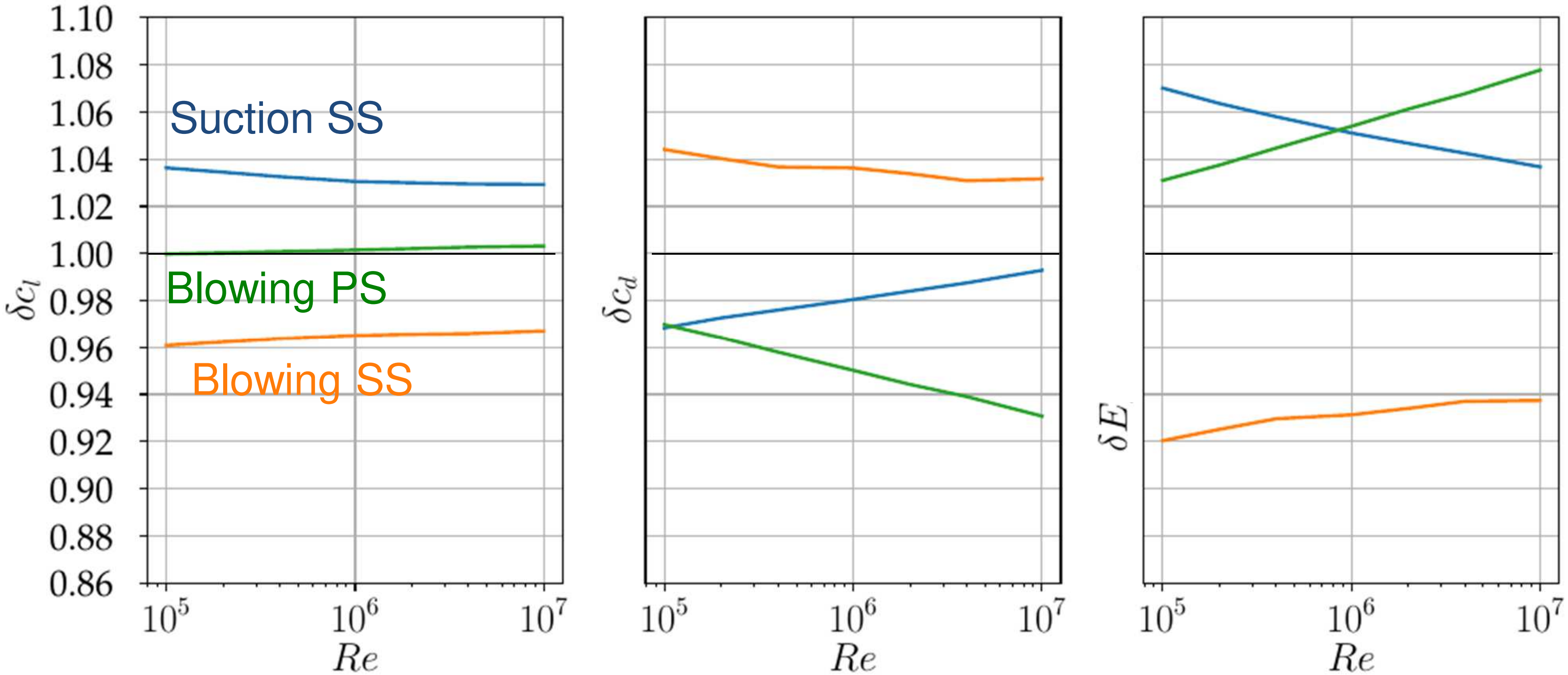
$$\delta\Phi = \frac{\Phi}{\Phi_{ref}}$$

$\approx \mathbf{10^5}$


[fatlion.com]

$\approx \mathbf{10^7}$


[Aviation History Museum]



Beneficial Blowing SS possible?

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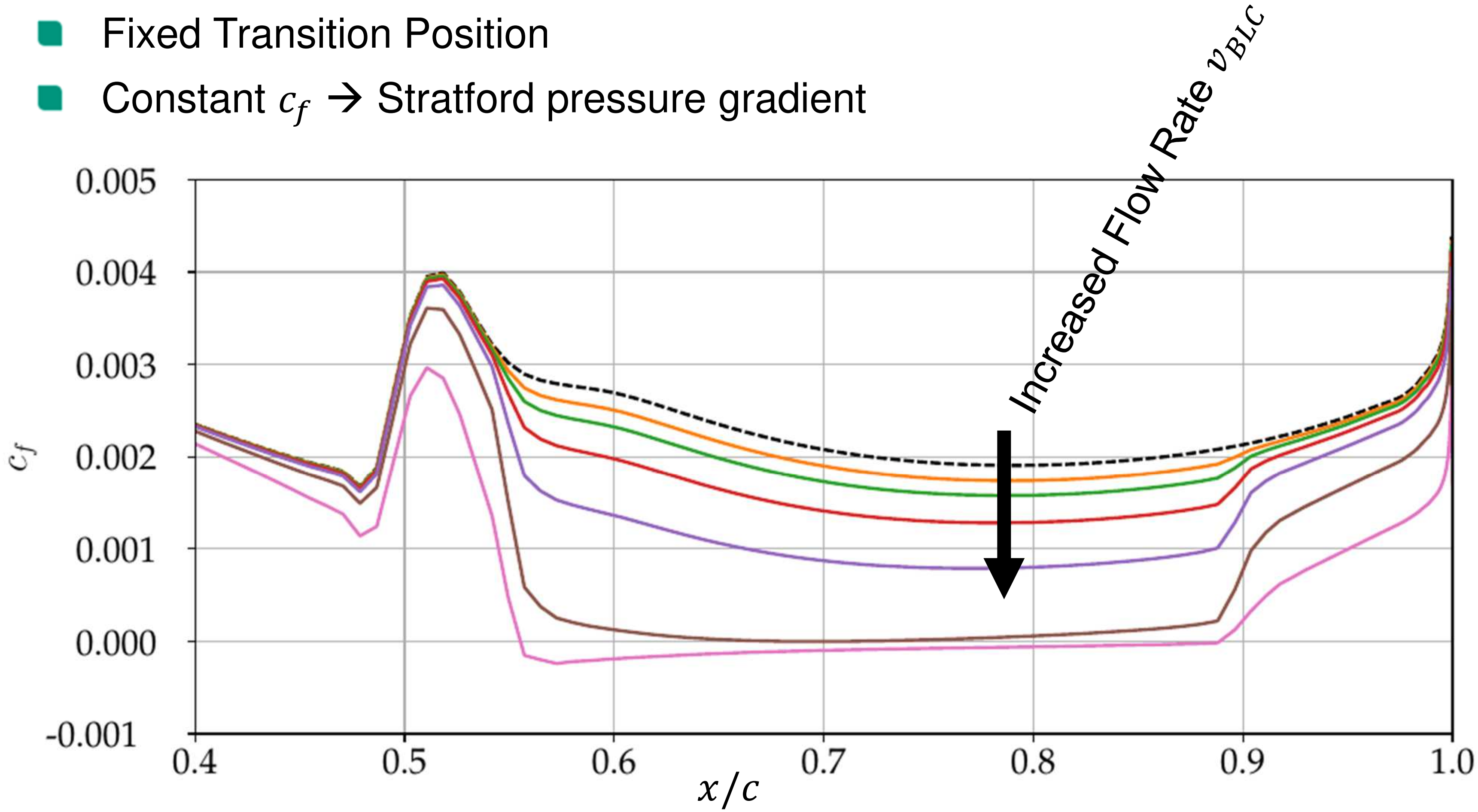
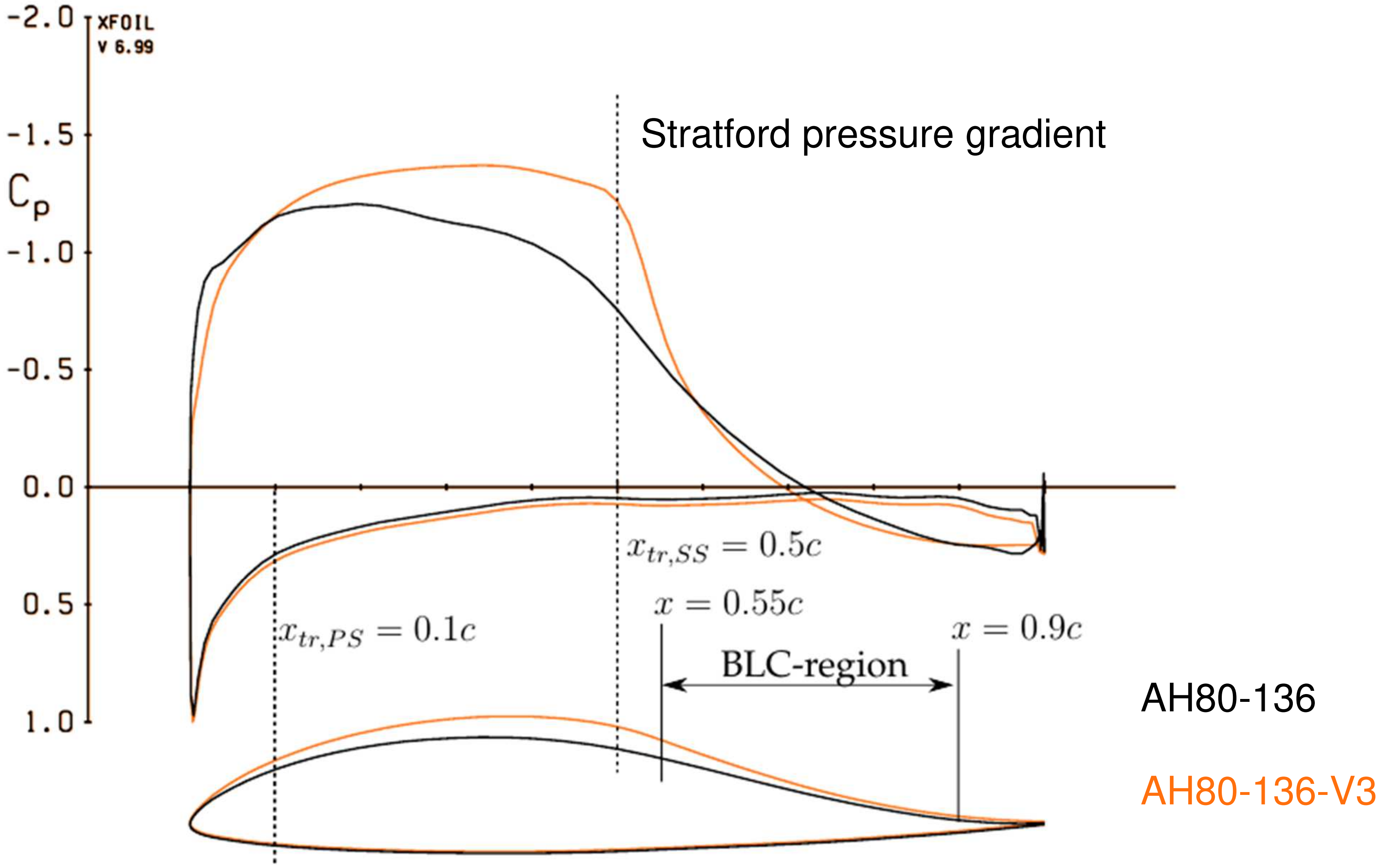
<u>What do we need?</u>

- Natural turbulent BL
- Fixed Transition Position
- Constant c_f → Stratford pressure gradient

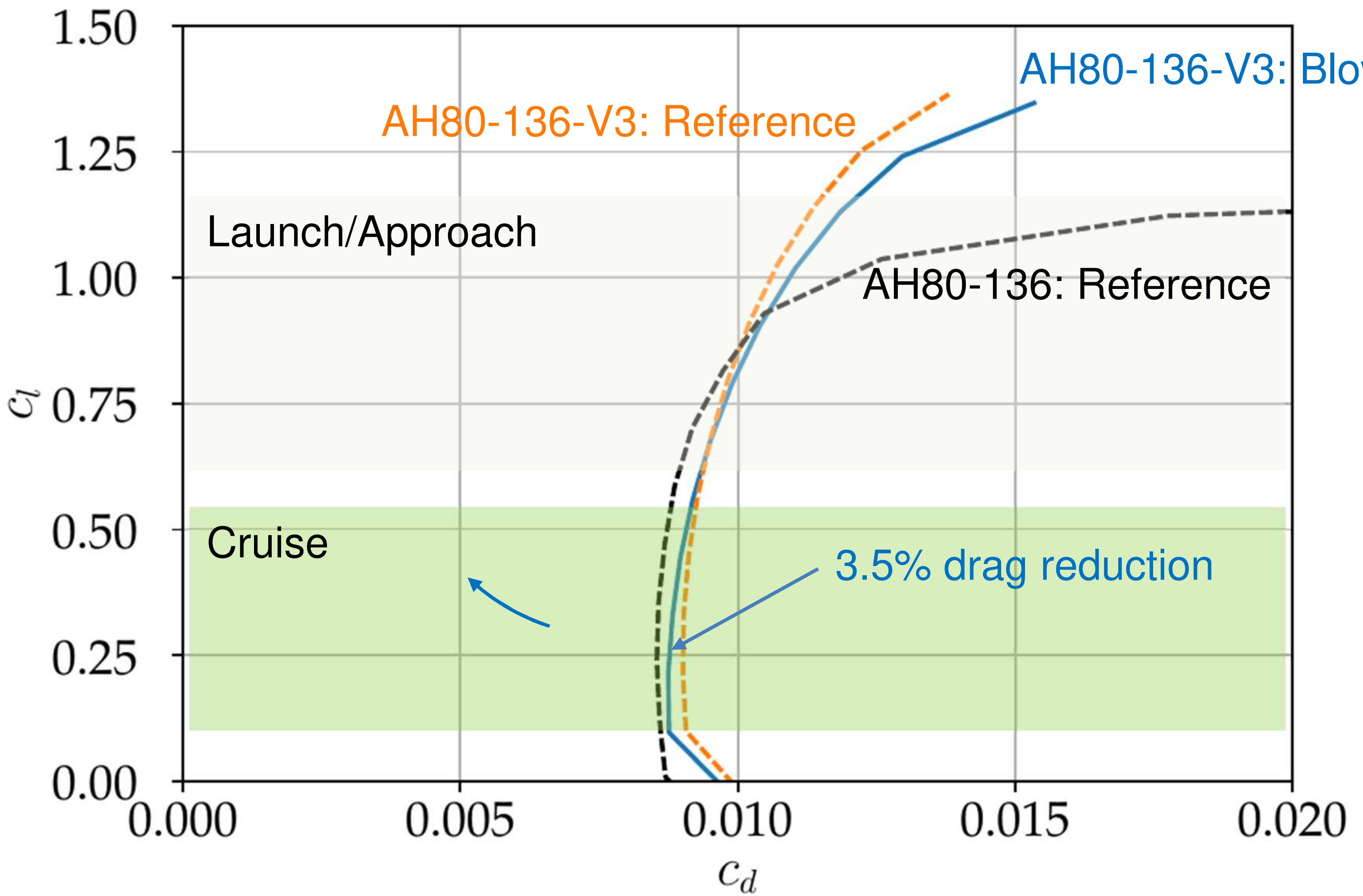


Beneficial Blowing SS possible?



Beneficial Blowing SS possible?

$Re = 10^6$



Conclusion / Lookout

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Summary:

- Beneficial in General:
  - Blowing for higher Re
  - Blowing PS for low c_l
  - Suction SS for high c_l
- Unfavorable
  - Suction for higher Re
  - Blowing SS
  - Suction PS
- Beneficial Blowing-on-SS-Setup also possible

Next steps of Interest:

- Higher Re and $Mach$
- More Airfoil types
  - Transonic (negatively S-shaped Camber-Line)
  - Airfoils with Flaps/Slats
- Airfoil geometry Matching BLC
- Unsteady Stall Assessment

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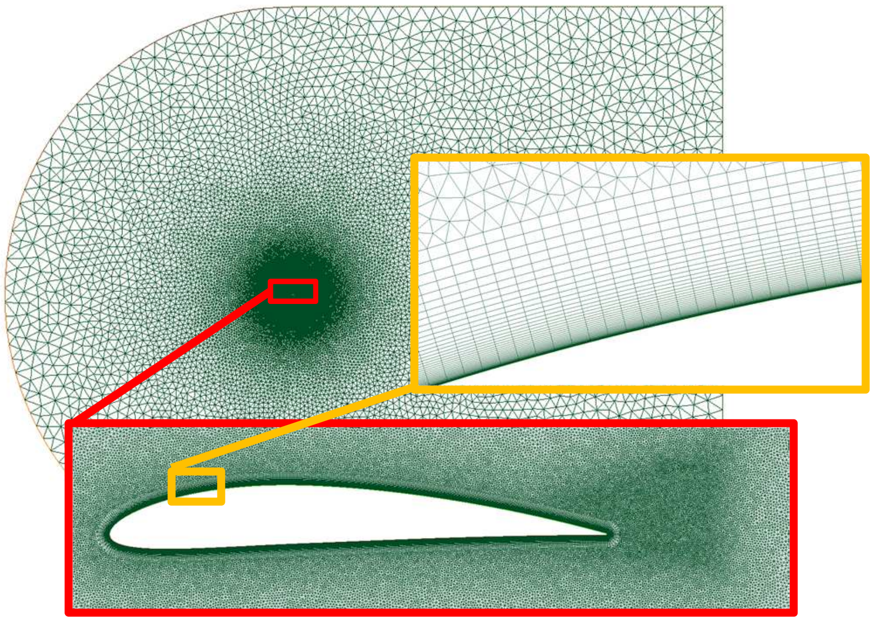
Varied Parameters

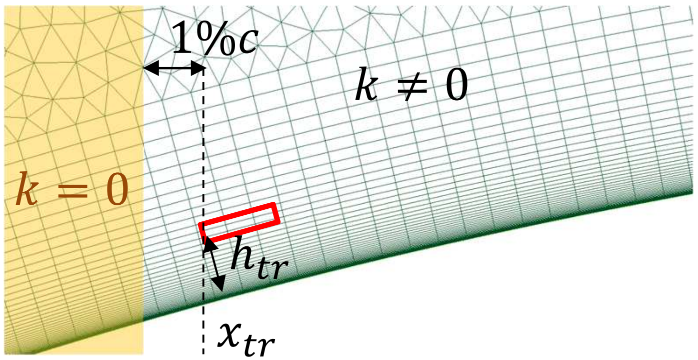
α [°]		-3 .. 12
Re		1e5 .. 2e7
Airfoil		Naca4412, Clark-Y, Naca23012, AH80-136
General Geometry	Camber	Naca5412, Naca6412
	Thickness	Naca4409, Naca4415
Flow Rate v_{BLC} [$\%u_\infty$]		0.025 .. 2
Configurations	Literature configurations	KTH
		Reder
		Fukagata
		Gersten
	Enhancements	Stratford Blowing Combined SS-Suction + PS-Blowing

Methodology – Mesh Generation

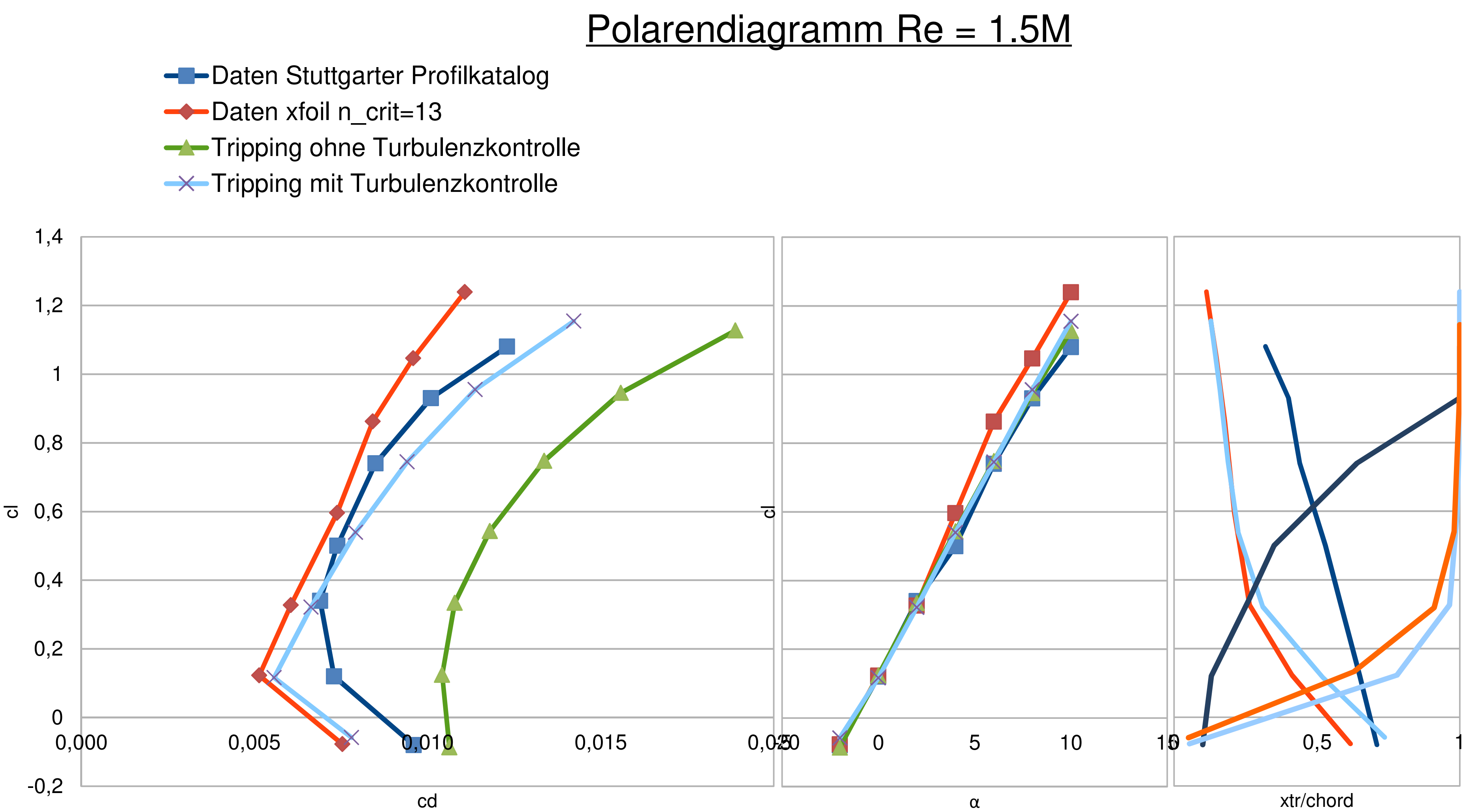
Matlab workflow:

1. Assessement of mesh requirements with XFOIL
   - $\tau_{max} \rightarrow h_{min}: y^+_{min} \approx 1$
   - $d_{Prism} = f(\delta_\theta, \alpha = 5°)$
   - $h_{tr} = f(\delta_\theta(\mathrm{x} = x_{tr}), \alpha = 5°)$
2. Meshing with gmsh
3. Transform to OpenFOAM
4. Generating control sets for transition handling





Validation – Experimental Data Naca23012



Agenda

1. Motivation/Objective
2. Methodology and Validation
3. Results:
   - α- dependency
   - Re- dependency
   - intensity- dependency
   - Influence of configurations