Blade and Rim Seal Design of a First Stage High Pressure Turbine for a 300 MWe Supercritical CO2 Power Cycle

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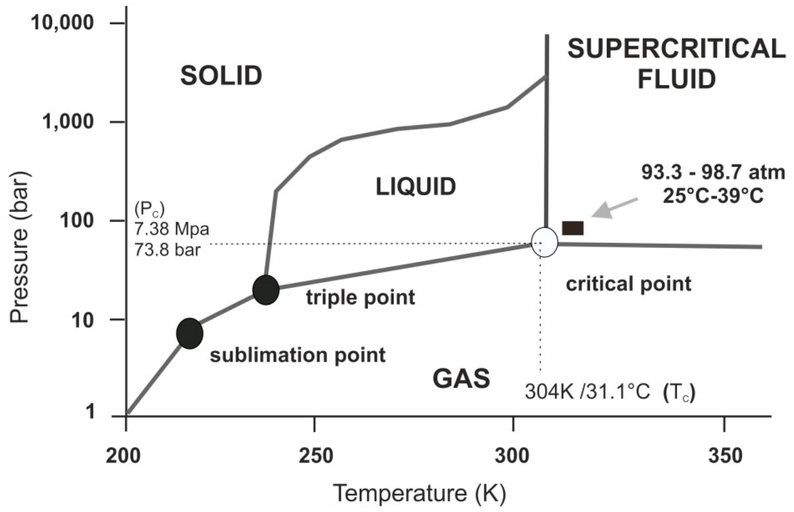
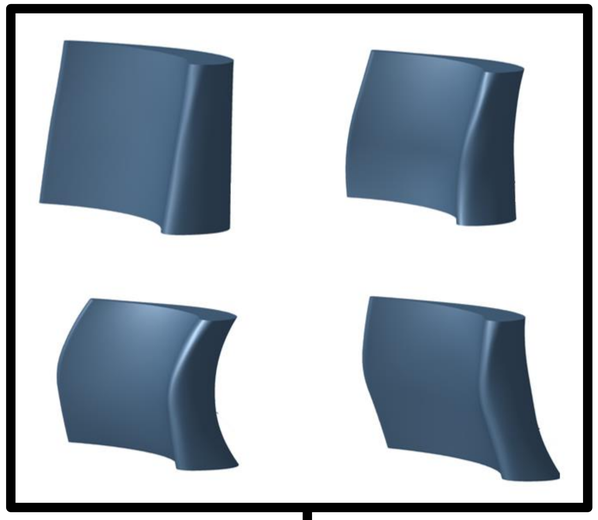
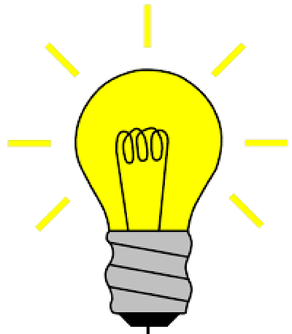
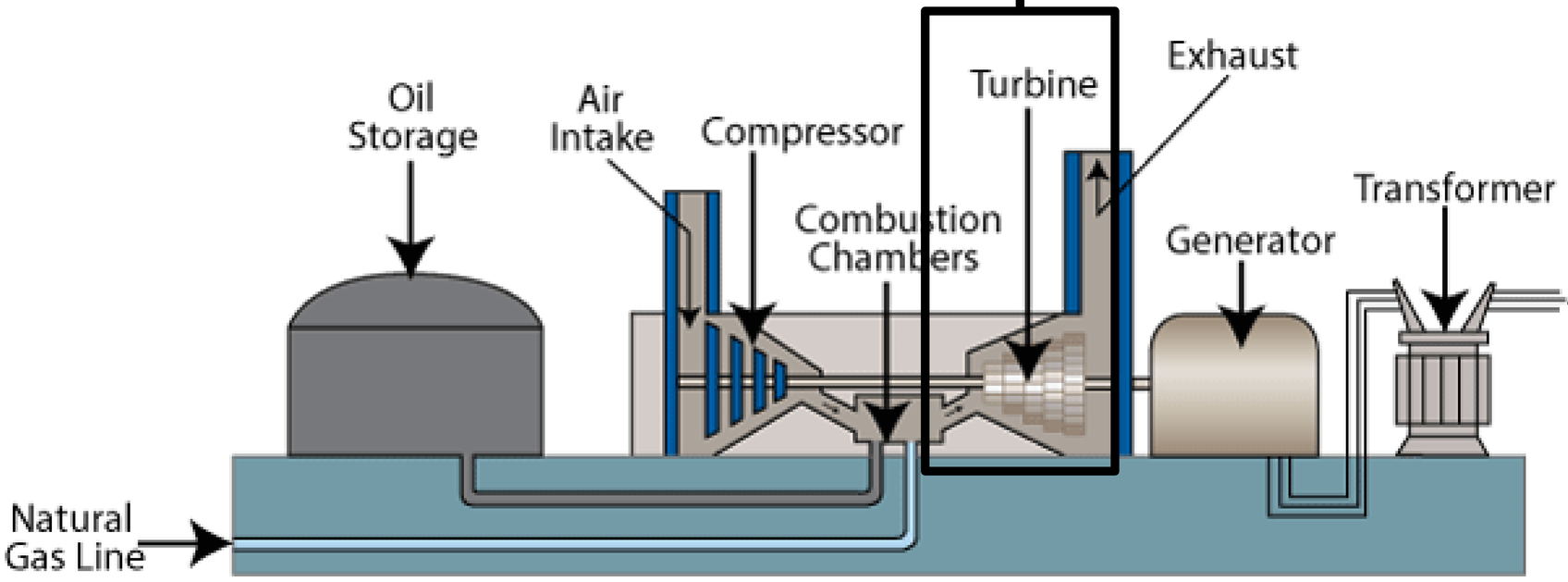
Track 5: Turbines – Tuesday, February 27, 2024 2:45 PM CT


10,000
1,000
100
10
1
Pressure (bar)
SOLID
SUPERCRITICAL FLUID
LIQUID
93.3 - 98.7 atm
25°C-39°C
(Pc)
7.38 Mpa
73.8 bar
triple point
critical point
sublimation point
GAS
304K /31.1°C (Tc)
200
250
300
350
Temperature (K)

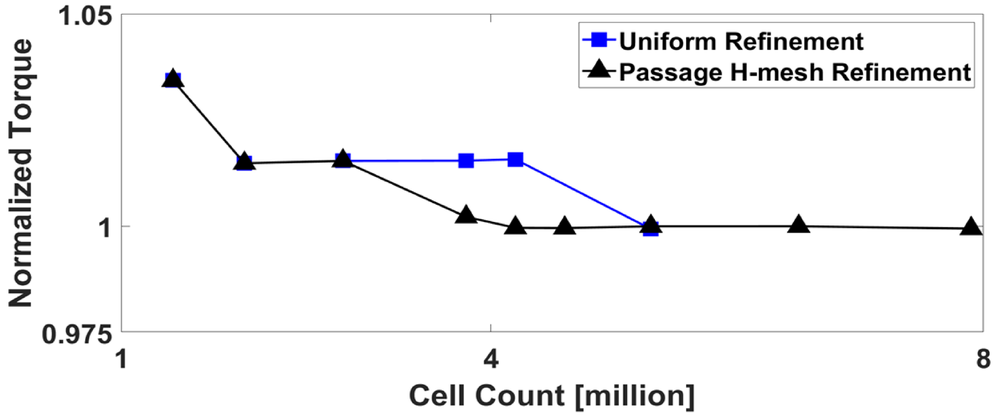


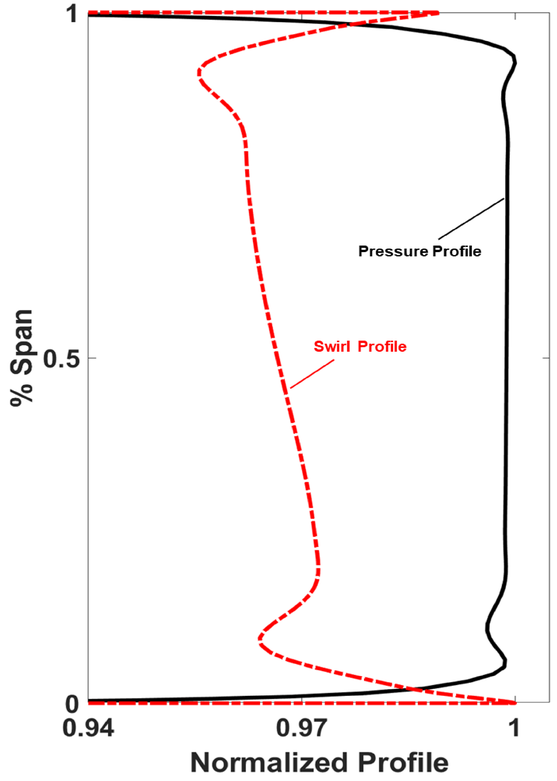



Oil Storage
Air Intake
Compressor
Combustion Chambers
Turbine
Exhaust
Generator
Transformer
Natural Gas Line

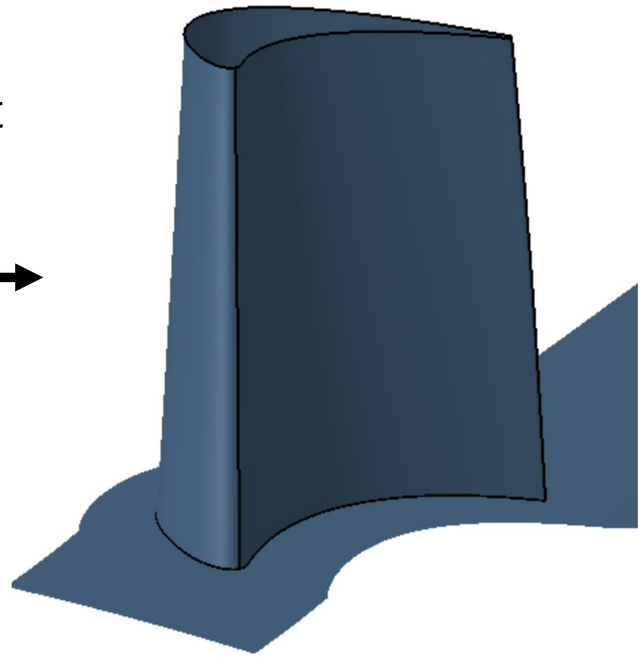
Outline

- Blade Aerothermal Optimization
- Squealer Rim Optimization
- Rim Seal Cavity Optimization
- Future Work
- Conclusions





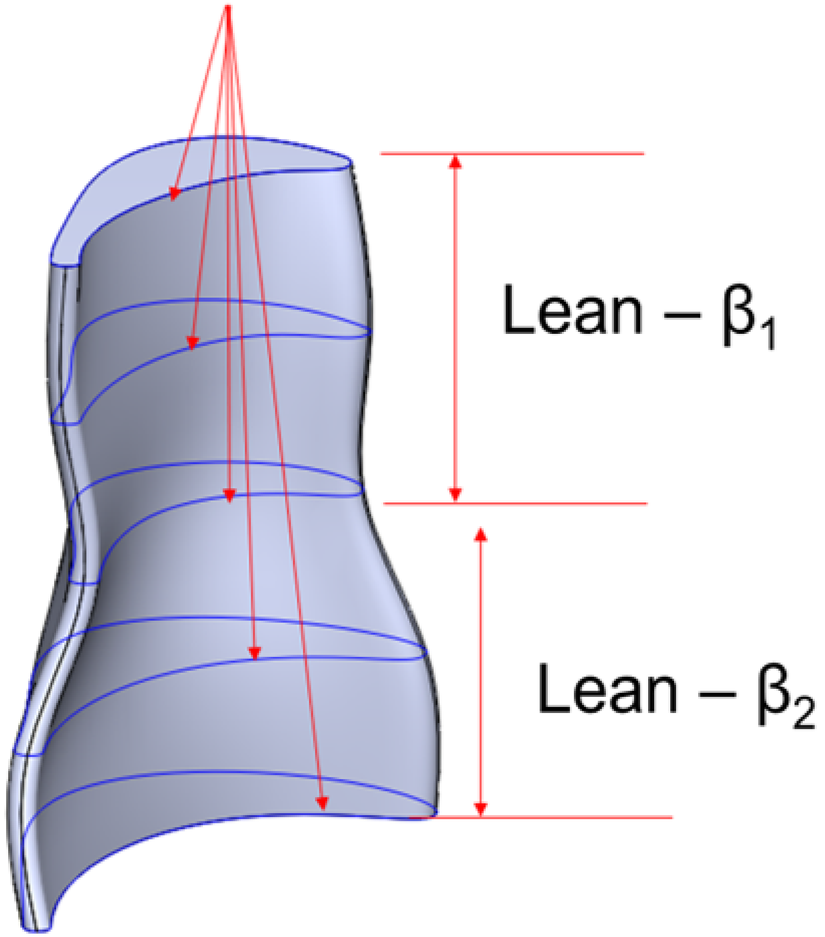
Applied Inlet Profiles



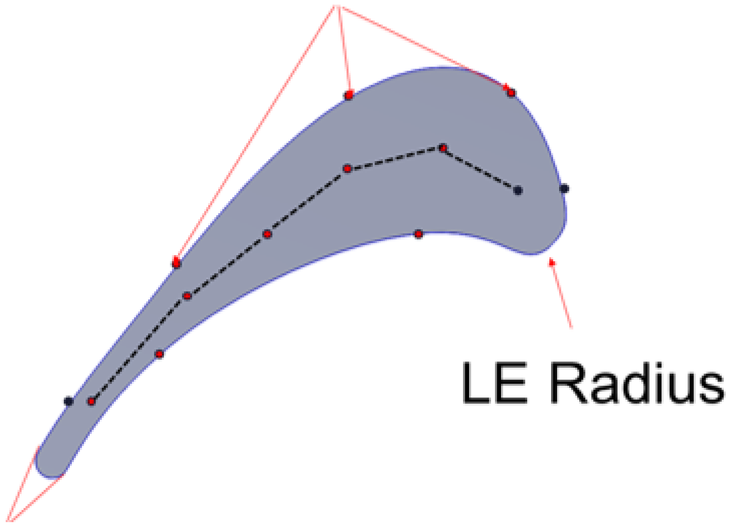
Parameter	Value
Aspect ratio	1.125
Hub-to-tip ratio	0.953
Pitch to chord ratio	1.05
Reynolds Number	$11*10^6$
$M_{inlet,\ relative\ rotor}$	0.207
$M_{exit,\ relative\ rotor}$	0.491
$\beta_{1,\ rotor}$	39.5 [deg]

Inlet/Exit Conditions	Value
$P_{02,\ r}$	303 [bar]
T_{02}	1420 [K]
$P_{02}/P_{3,\ s}$	1.389

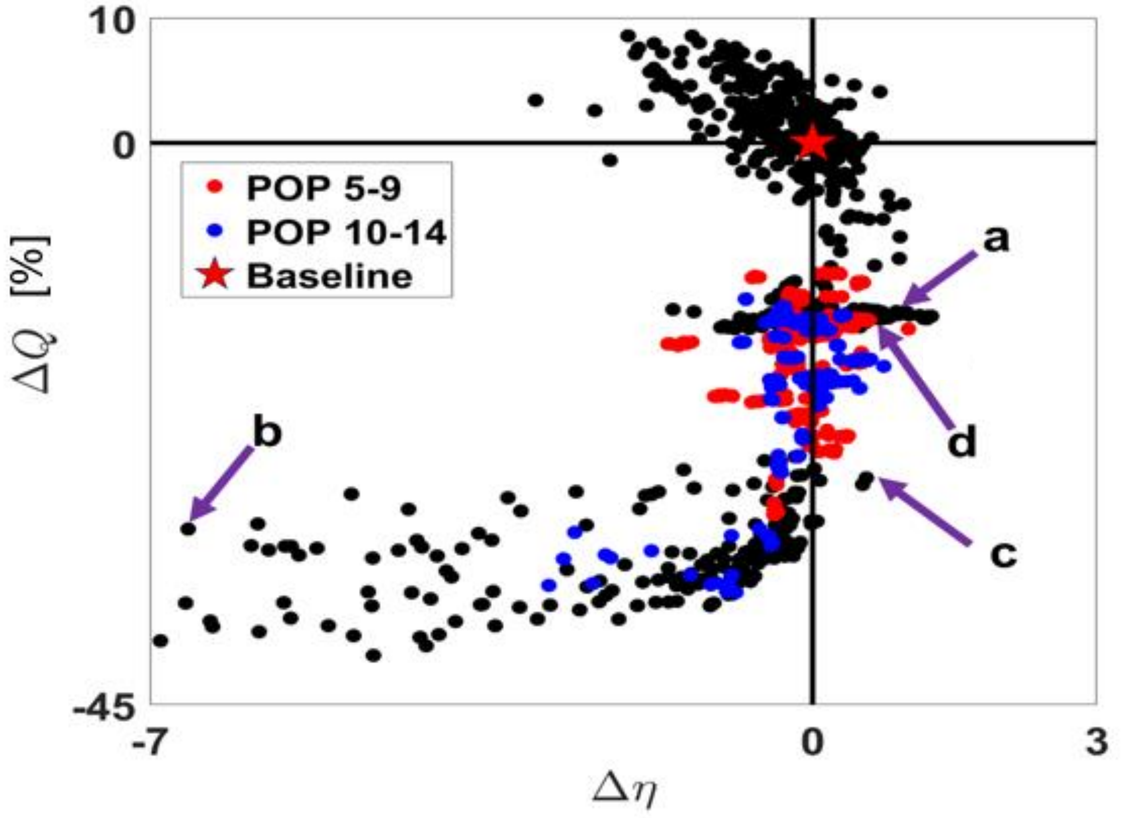
5 Airfoil Sections

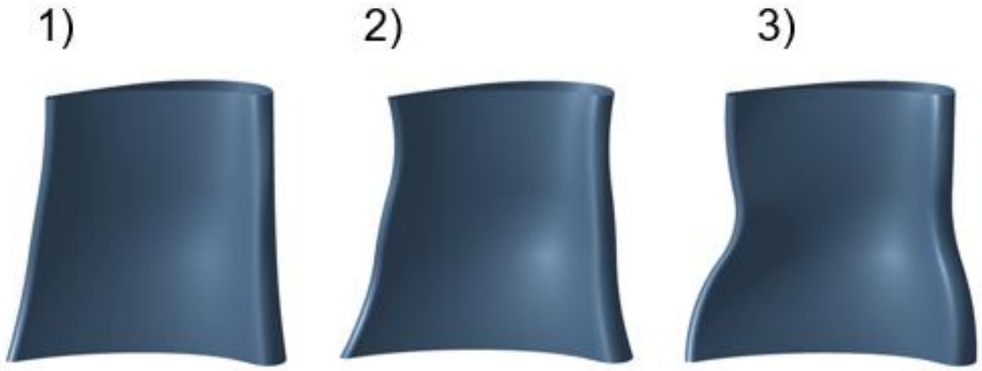


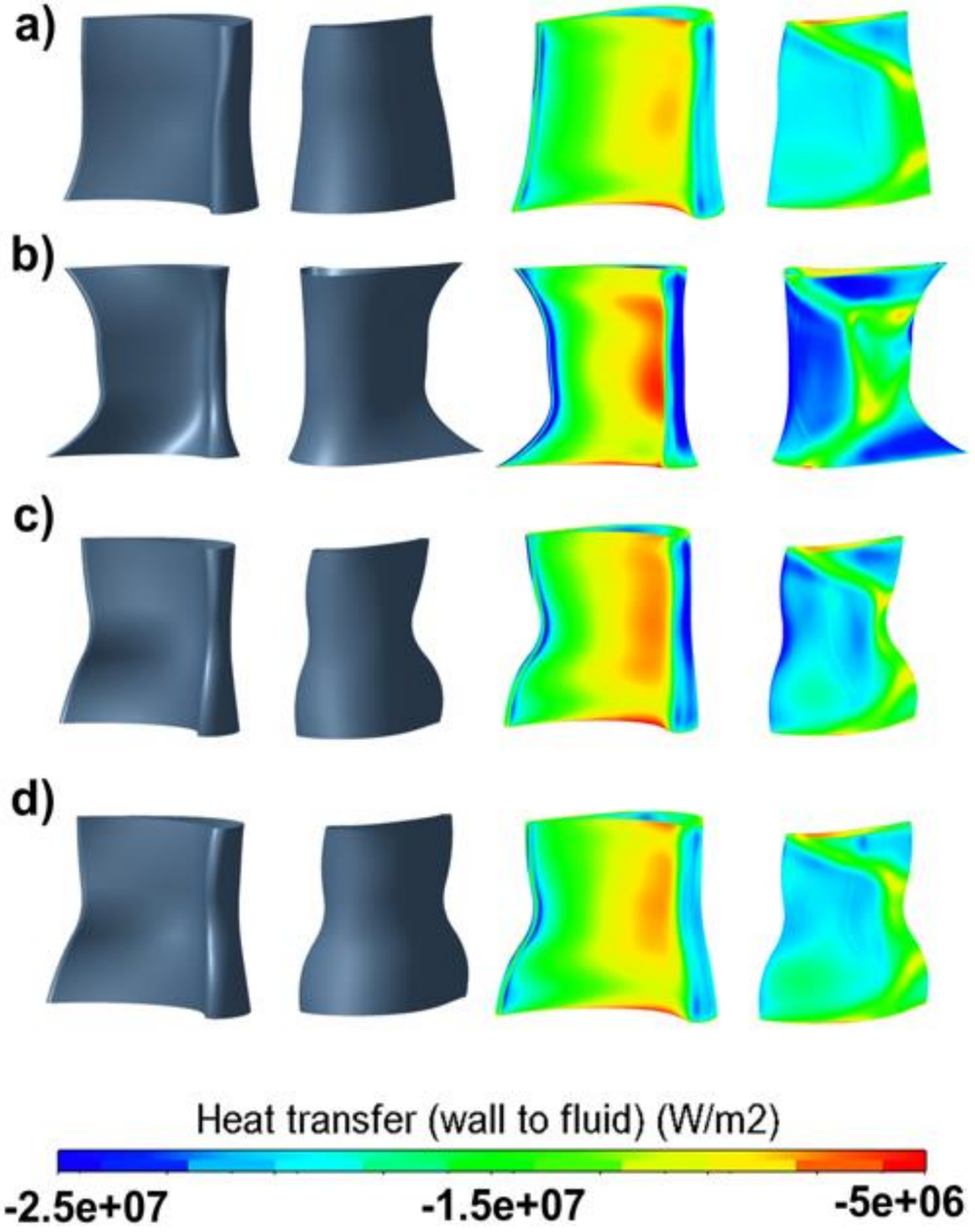
Bezier Control Points

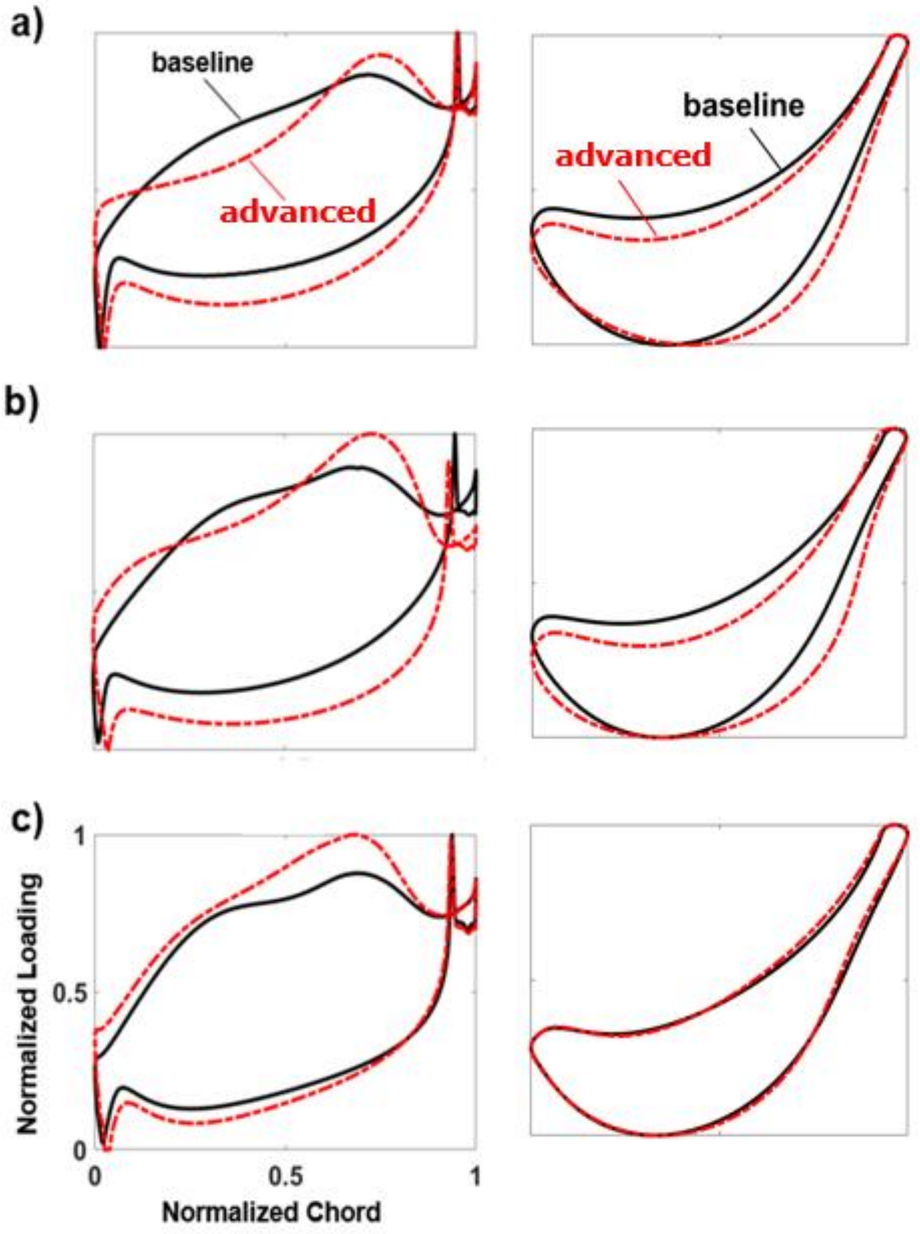


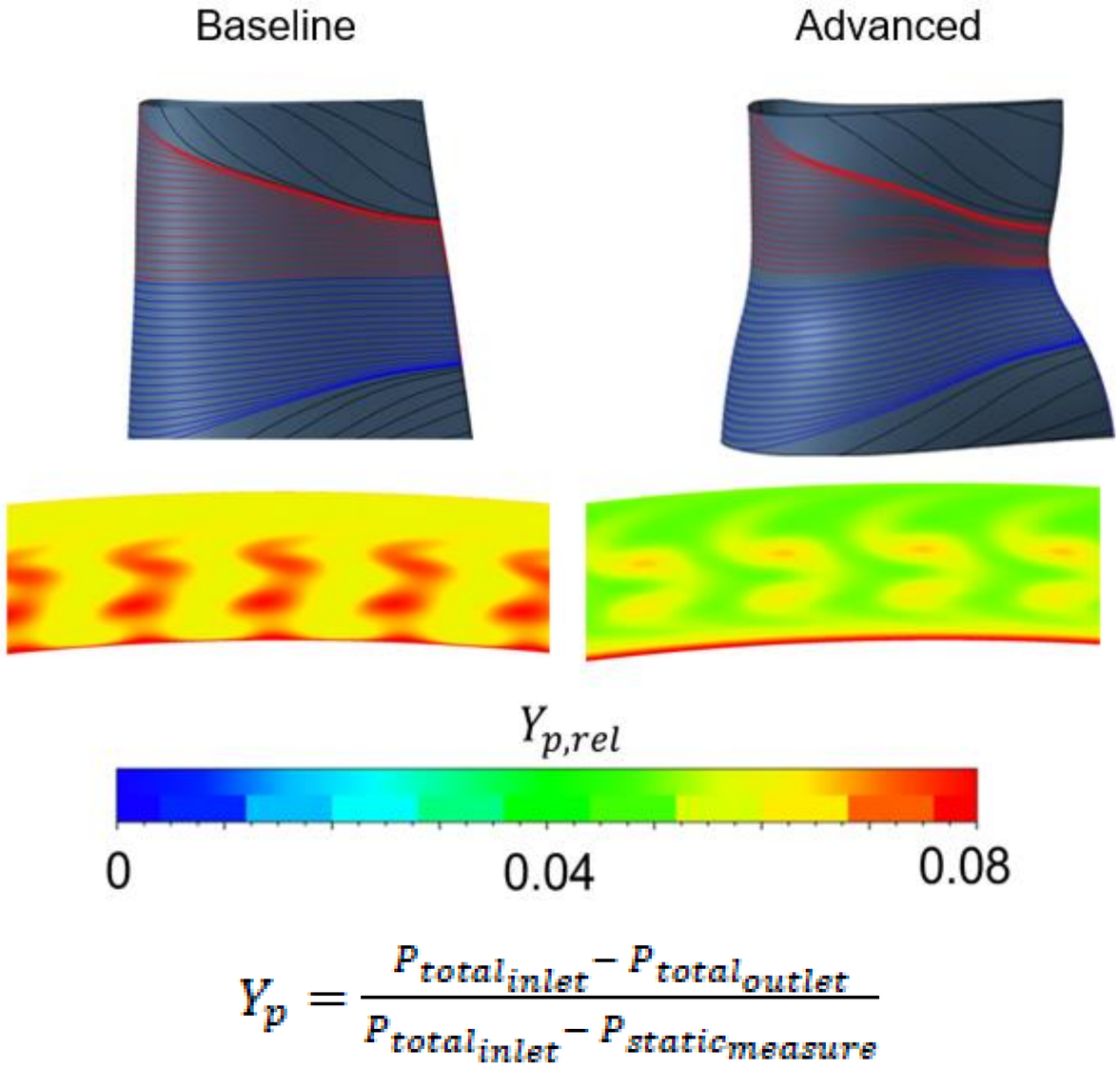
Parameter	Degrees of Freedom	Bounds
Spanwise locations	5	0, 25, 50, 75, 100 [%]
Camber line	5	+/- 10%
LE radius	1	+/- 10%
SS Bezier	3	+/- 0.1
PS Bezier	2	+/- 0.1
TE wedge angle	1	+-/ 10%
Sweep angle	1	+-/ 10%
Stacking sweep point	1	+-/ 10%
Sweep meridional position	5	+-/ 10%
0-50% span lean angle	1	+-/ 10%
50-100% span lean angle	1	+-/ 10%
Blade rotation	1	+-/ 5 [deg]


10
0
-45
-7
0
3
ΔQ [%]
Δη
POP 5-9
POP 10-14
Baseline
a
b
c
d

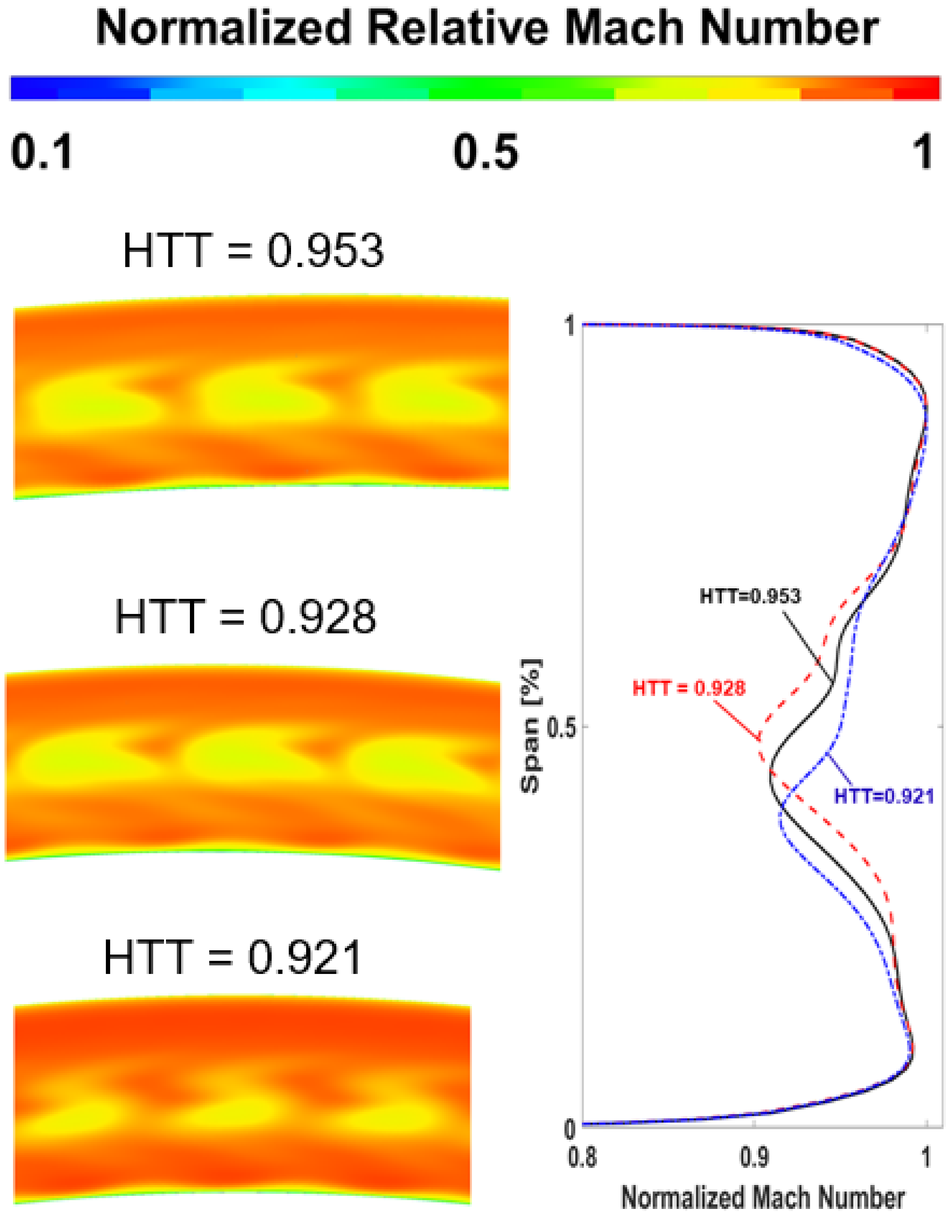

1)
2)
3)

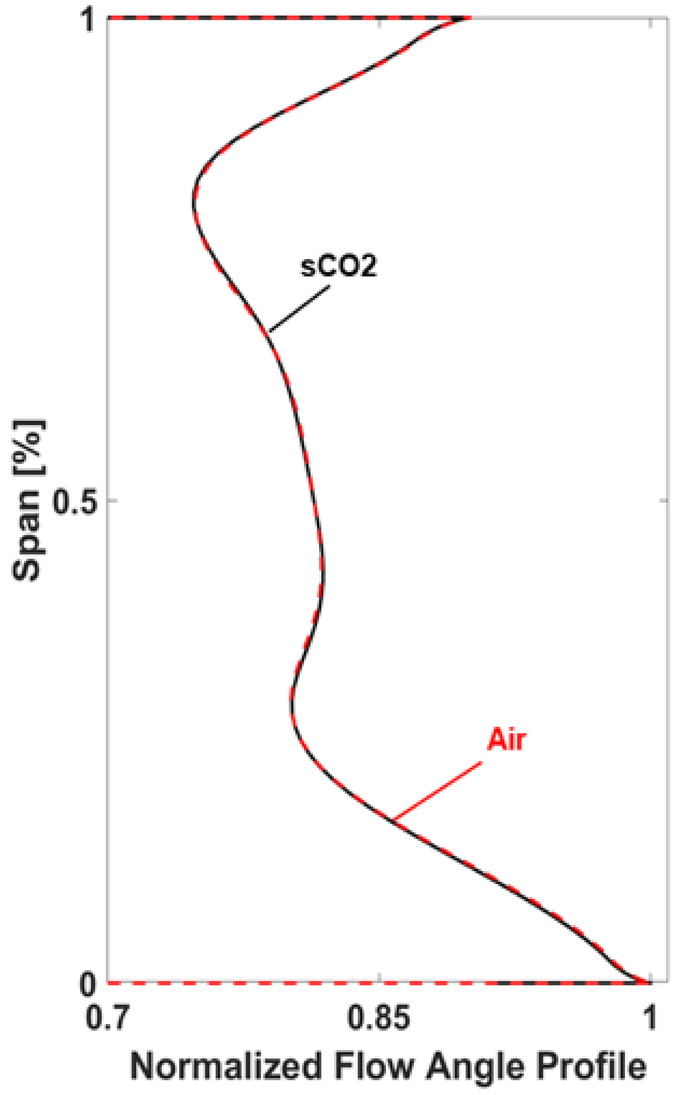

a)
b)
c)
d)
Heat transfer (wall to fluid) (W/m2)
-2.5e+07
-1.5e+07
-5e+06

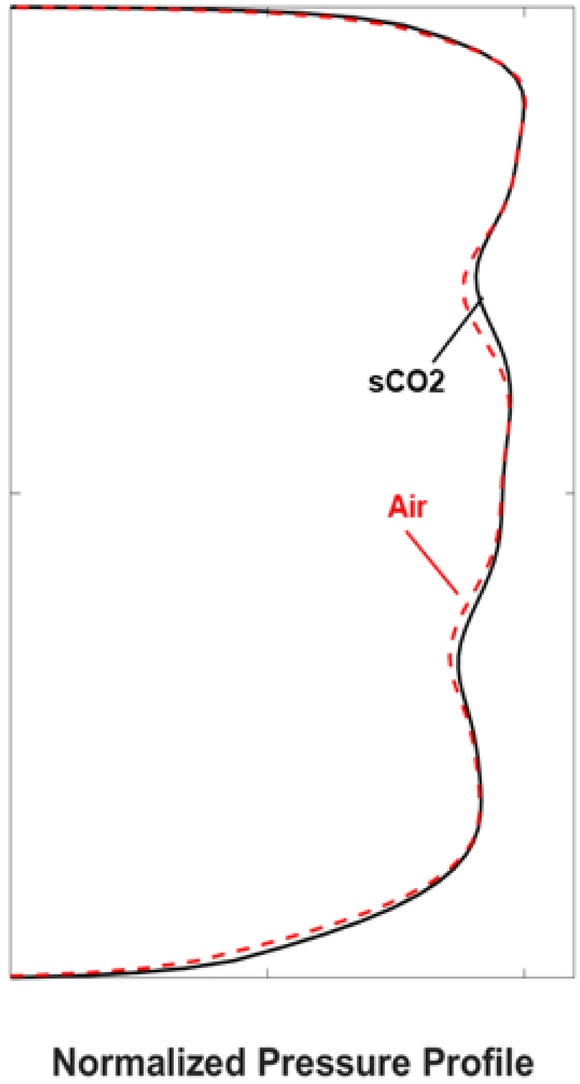


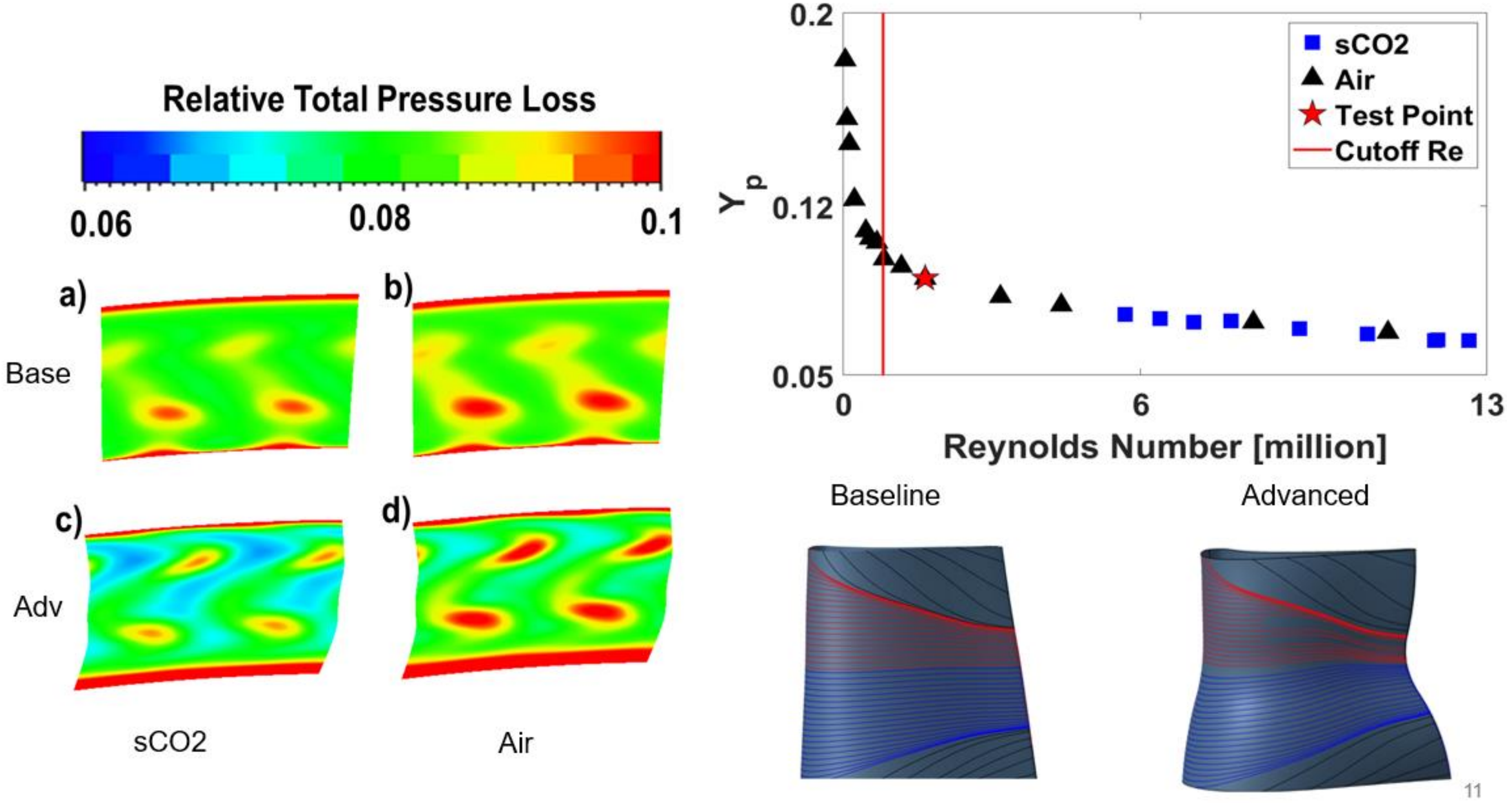


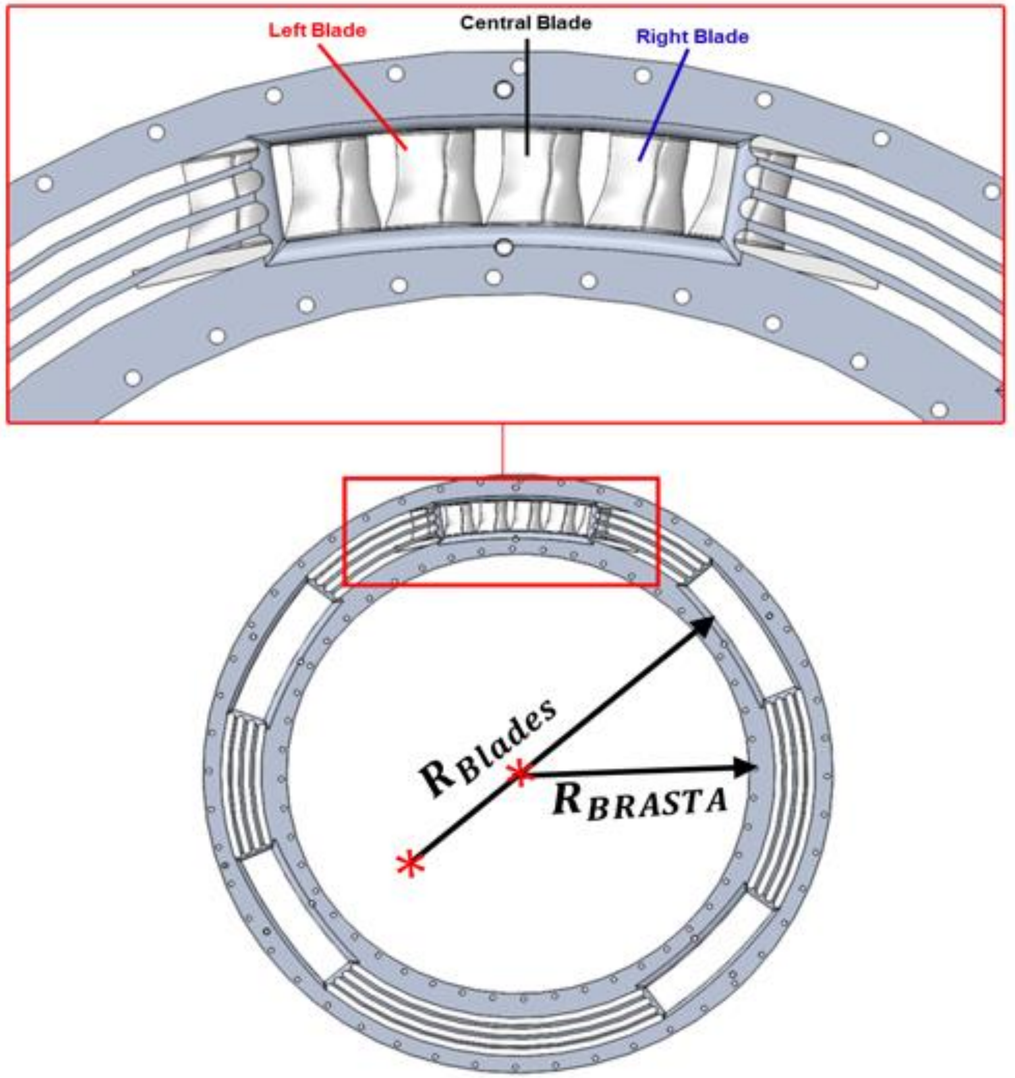
$$Y_p = \frac{P_{total_{inlet}} - P_{total_{outlet}}}{P_{total_{inlet}} - P_{static_{measure}}}$$

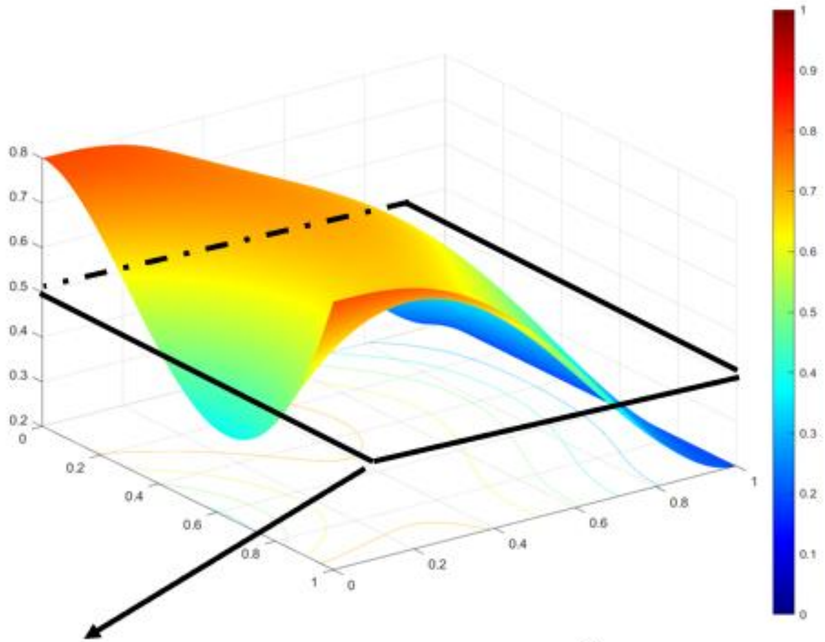

Normalized Relative Mach Number
0.1
0.5
1
HTT = 0.953
HTT = 0.928
HTT = 0.921
HTT=0.953
HTT = 0.928
HTT=0.921
Span [%]
Normalized Mach Number
1
0.5
0
0.8
0.9
1

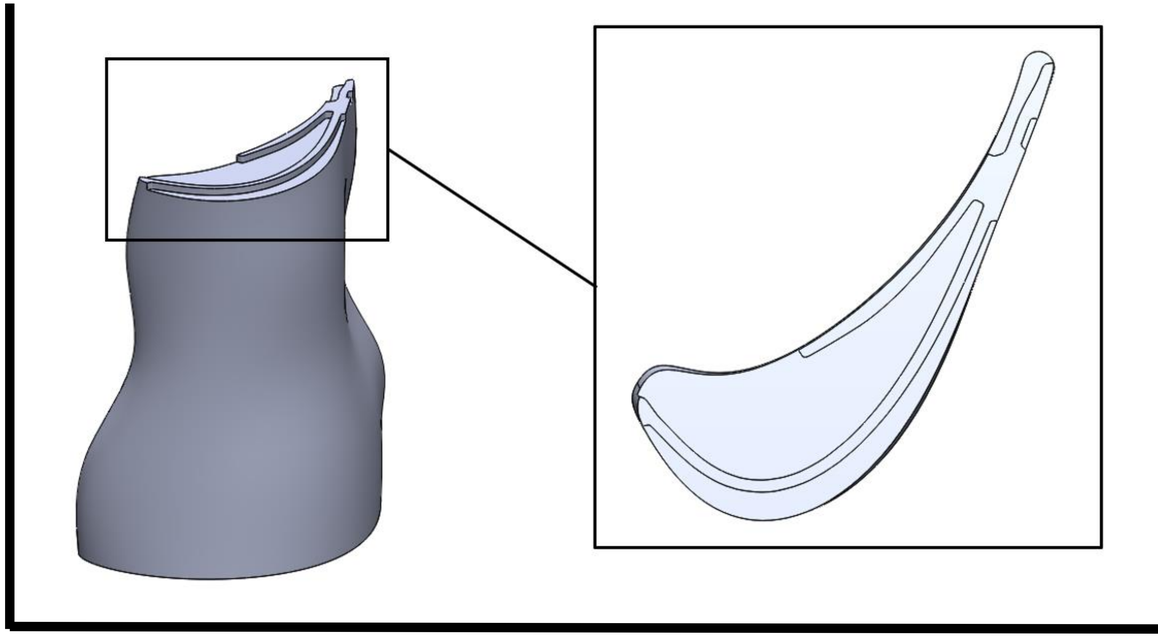

sCO2
Air
Span [%]
Normalized Flow Angle Profile
1
0.5
0
0.7
0.85
1

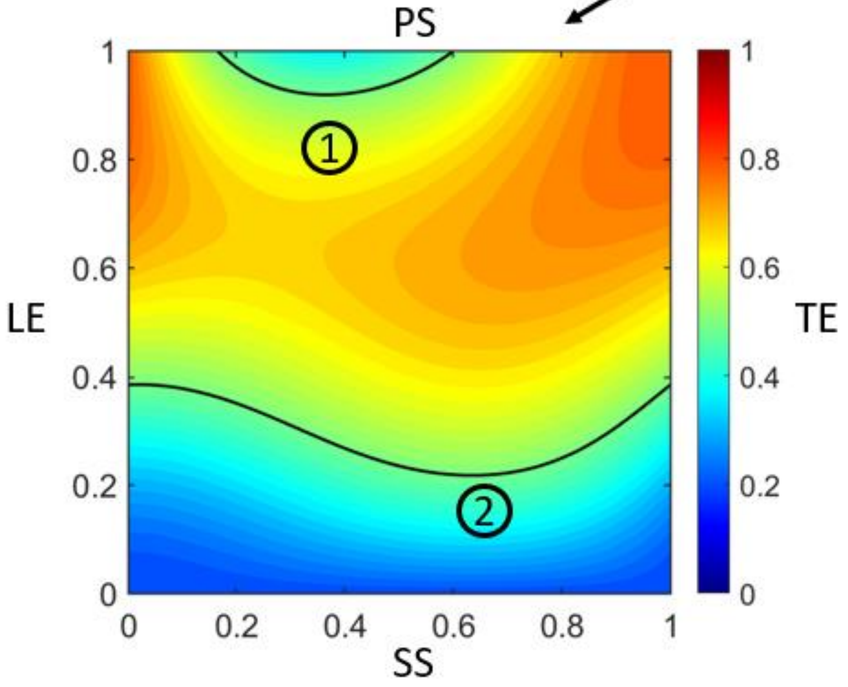

sCO2
Air
Normalized Pressure Profile

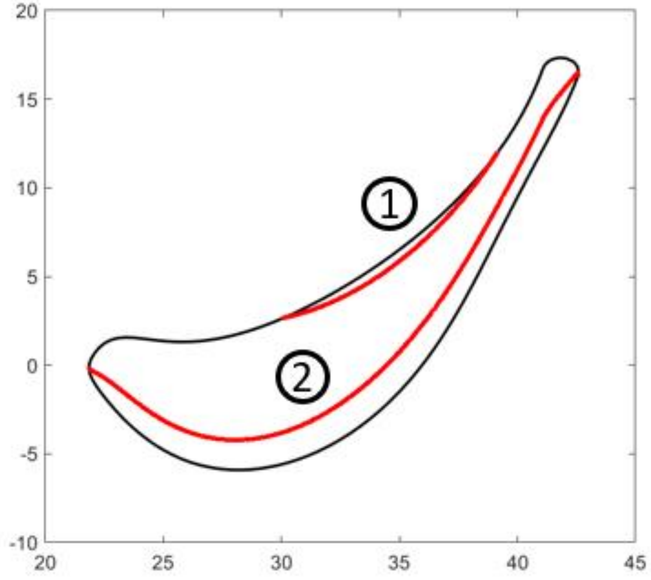

Relative Total Pressure Loss
0.06
0.08
0.1
a)
b)
Base
c)
d)
Adv
sCO2
Air
0.2
0.12
0.05
Y_p
0
6
13
Reynolds Number [million]
sCO2
Air
Test Point
Cutoff Re
Baseline
Advanced

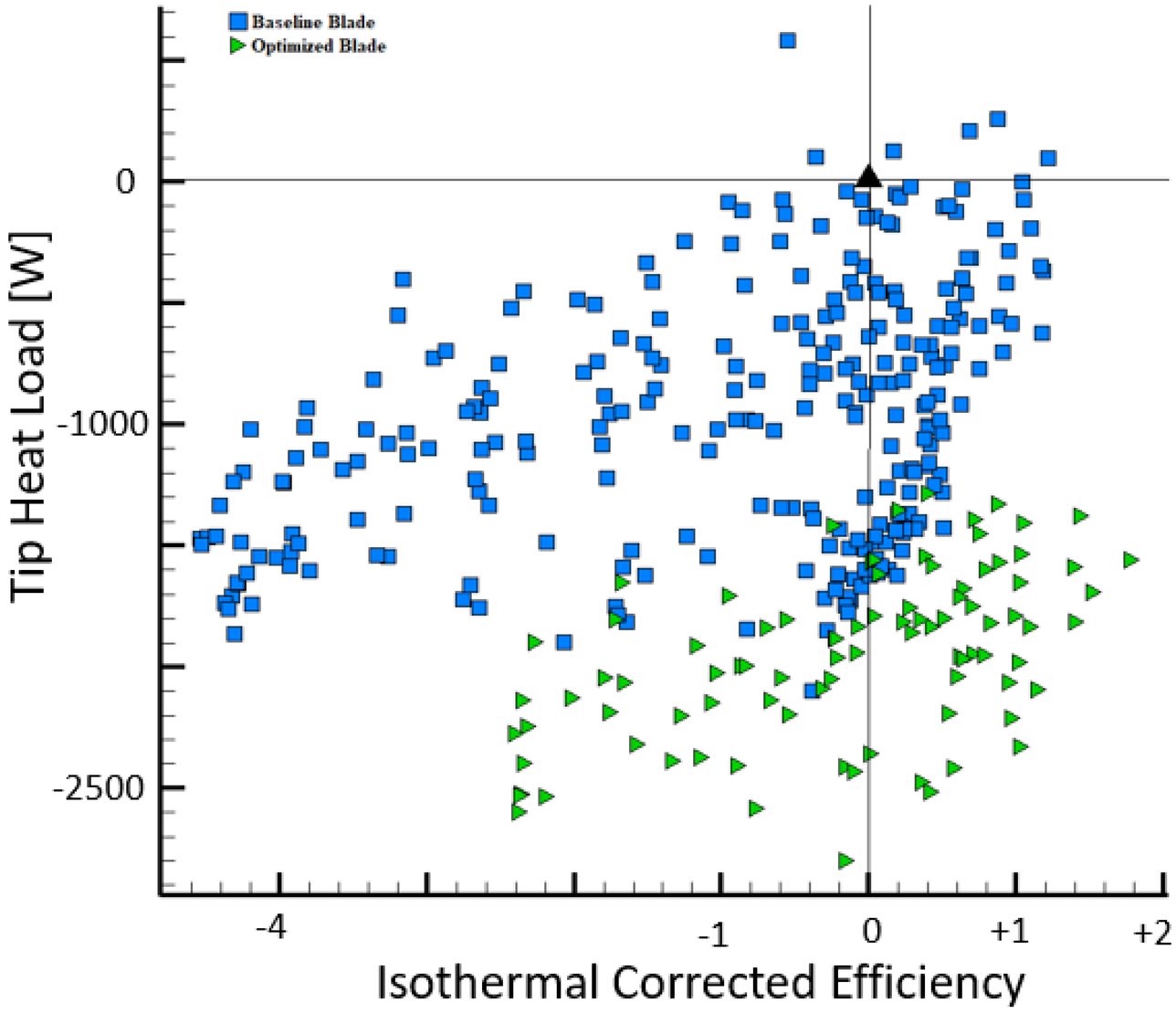

Left Blade
Central Blade
Right Blade
R_{Blades}
R_{BRASTA}

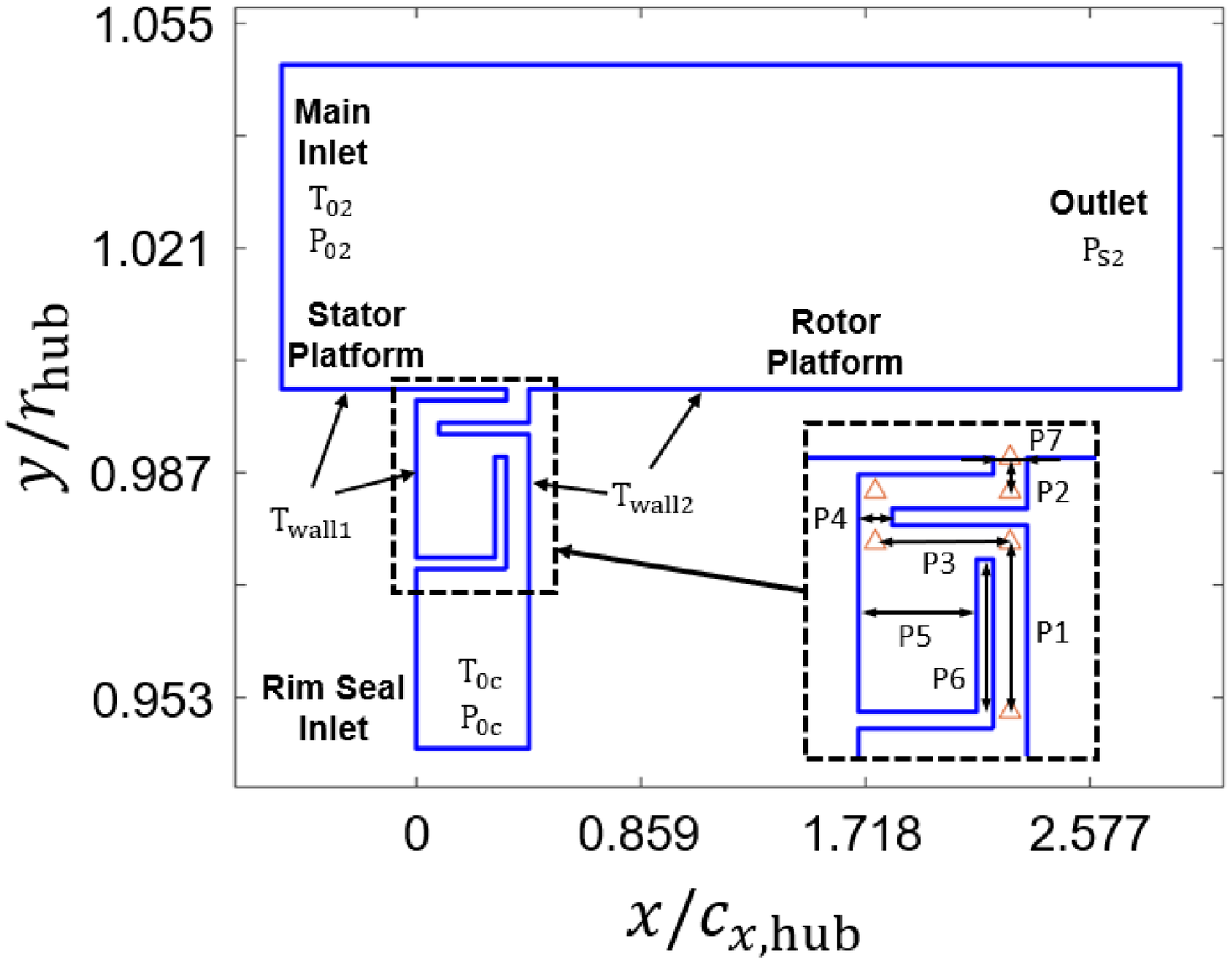





PS
LE
TE
SS
1
2

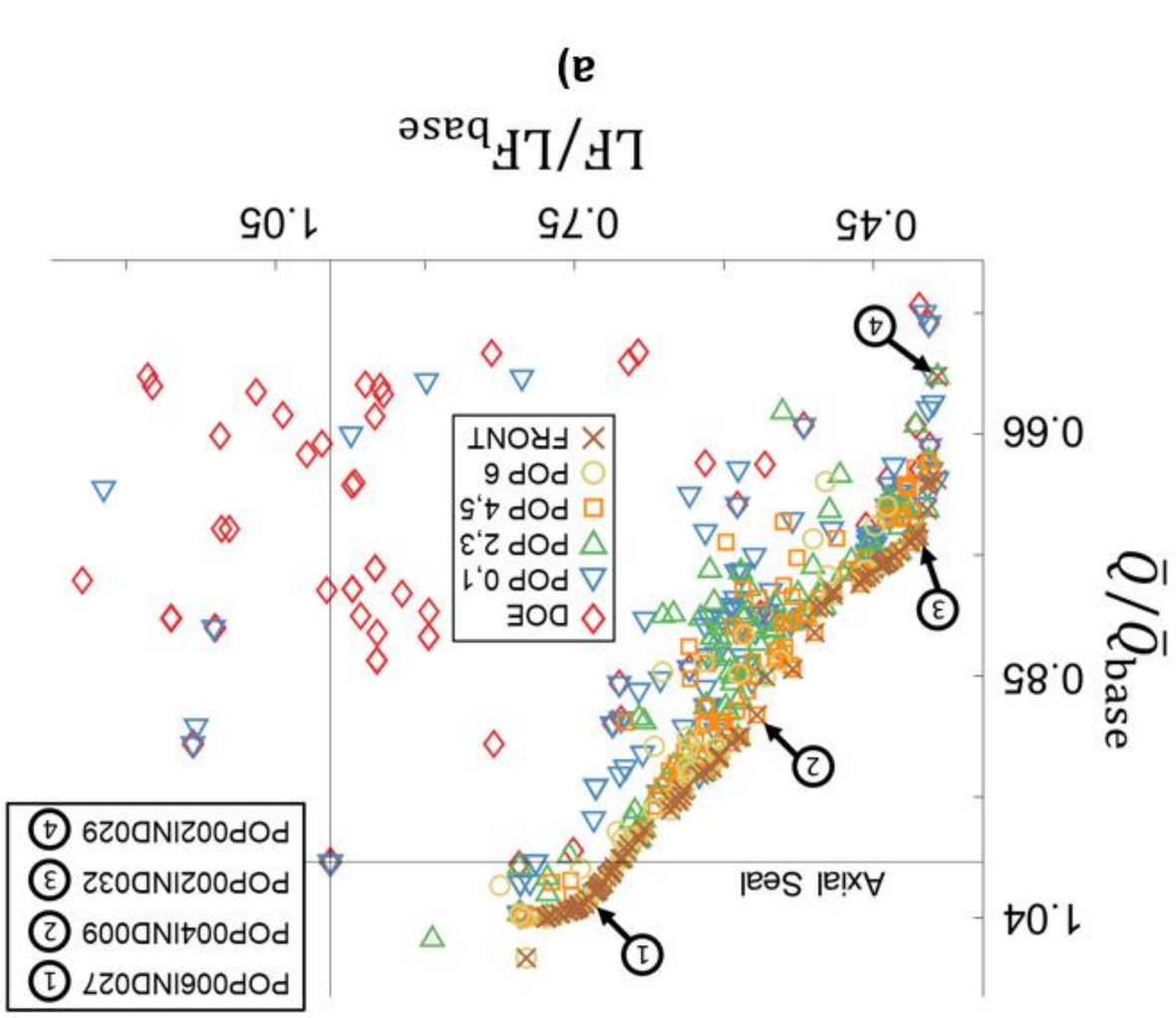

1
2

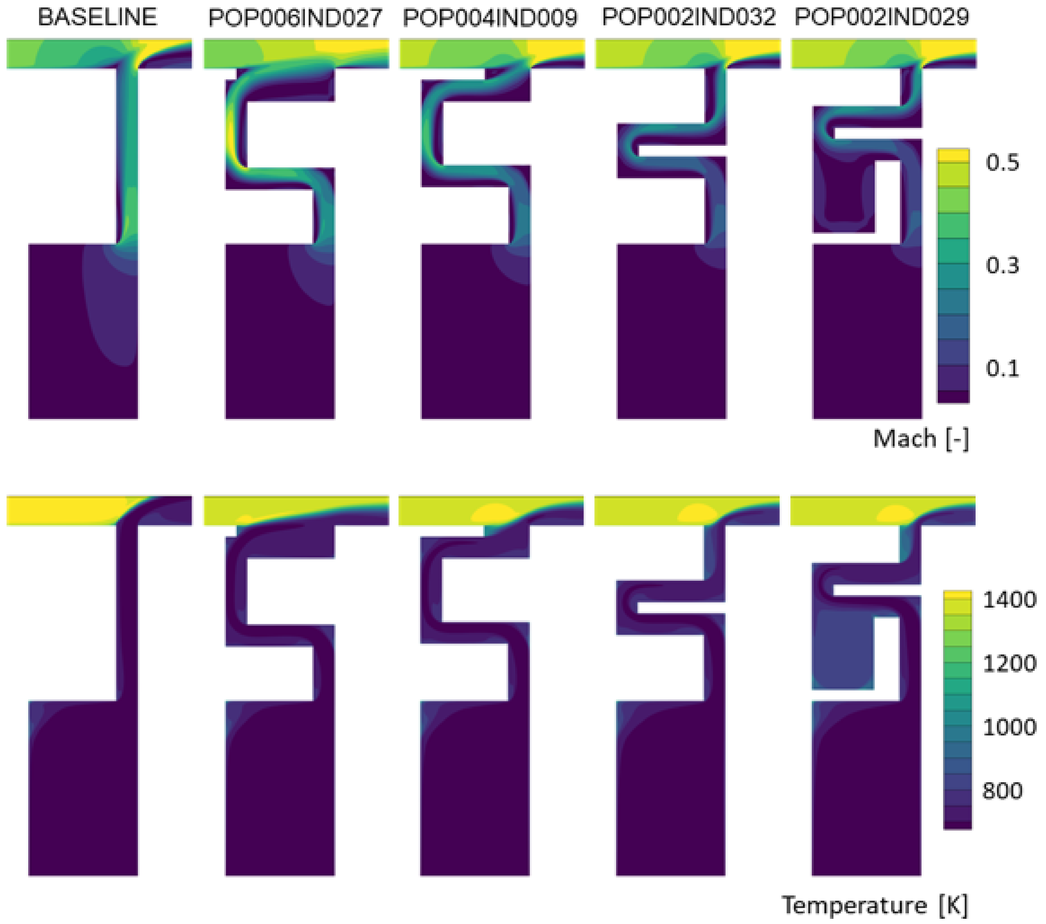

Baseline Blade
Optimized Blade
0
-1000
-2500
Tip Heat Load [W]
-4
-1
0
+1
+2
Isothermal Corrected Efficiency



$$F_1 = \min\left\{\frac{\dot{m}_{\mathrm{seal,in}}}{\dot{m}_{\mathrm{channel,in}}}\right\} = \min\{\mathrm{LF}\}$$

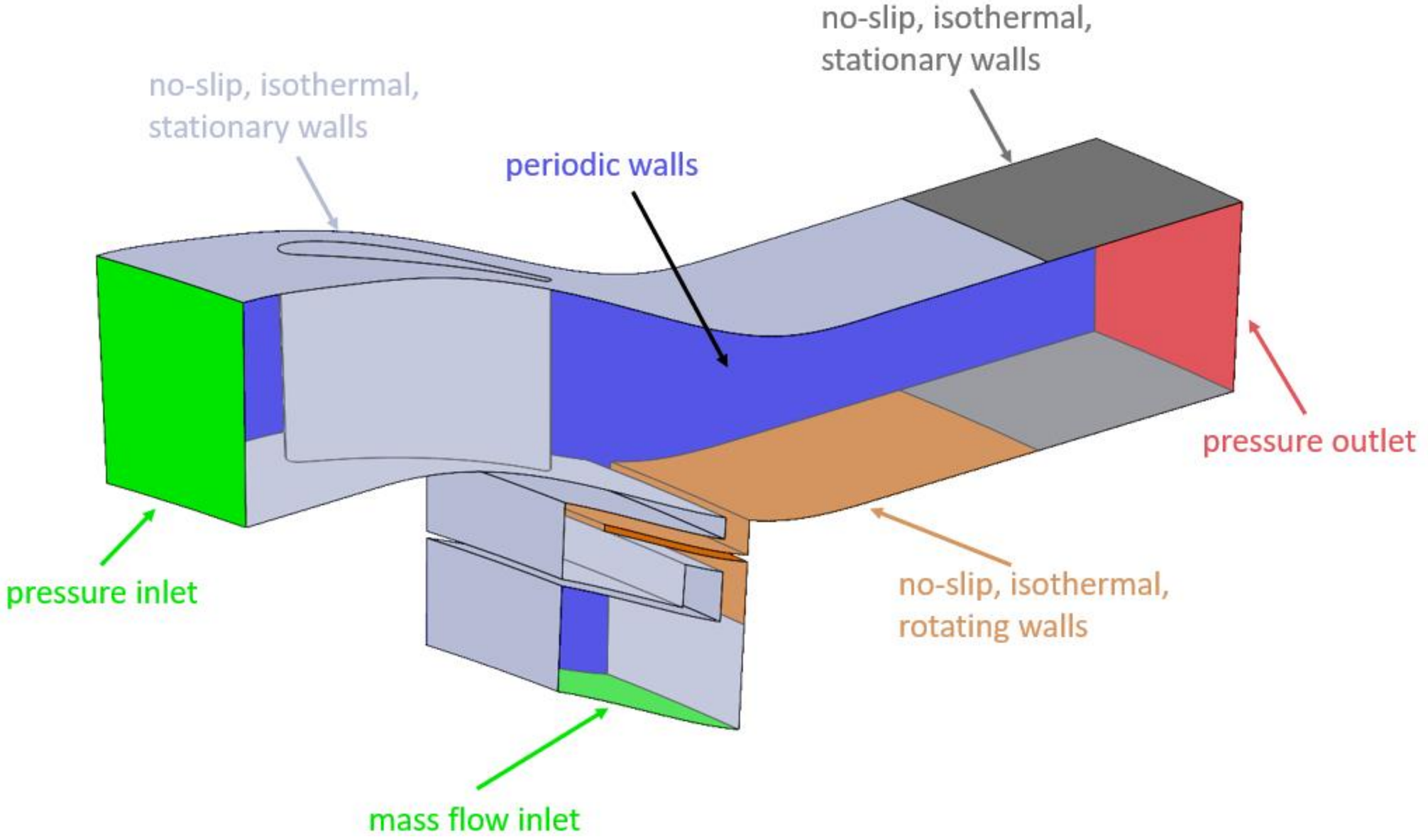
$$F_2 = \max\left\{\frac{Q_{\mathrm{seal,stator}}}{L_{\mathrm{seal,stator}}} + \frac{Q_{\mathrm{seal,rotor}}}{L_{\mathrm{seal,rotor}}}\right\} = \max\{\bar{Q}\}$$

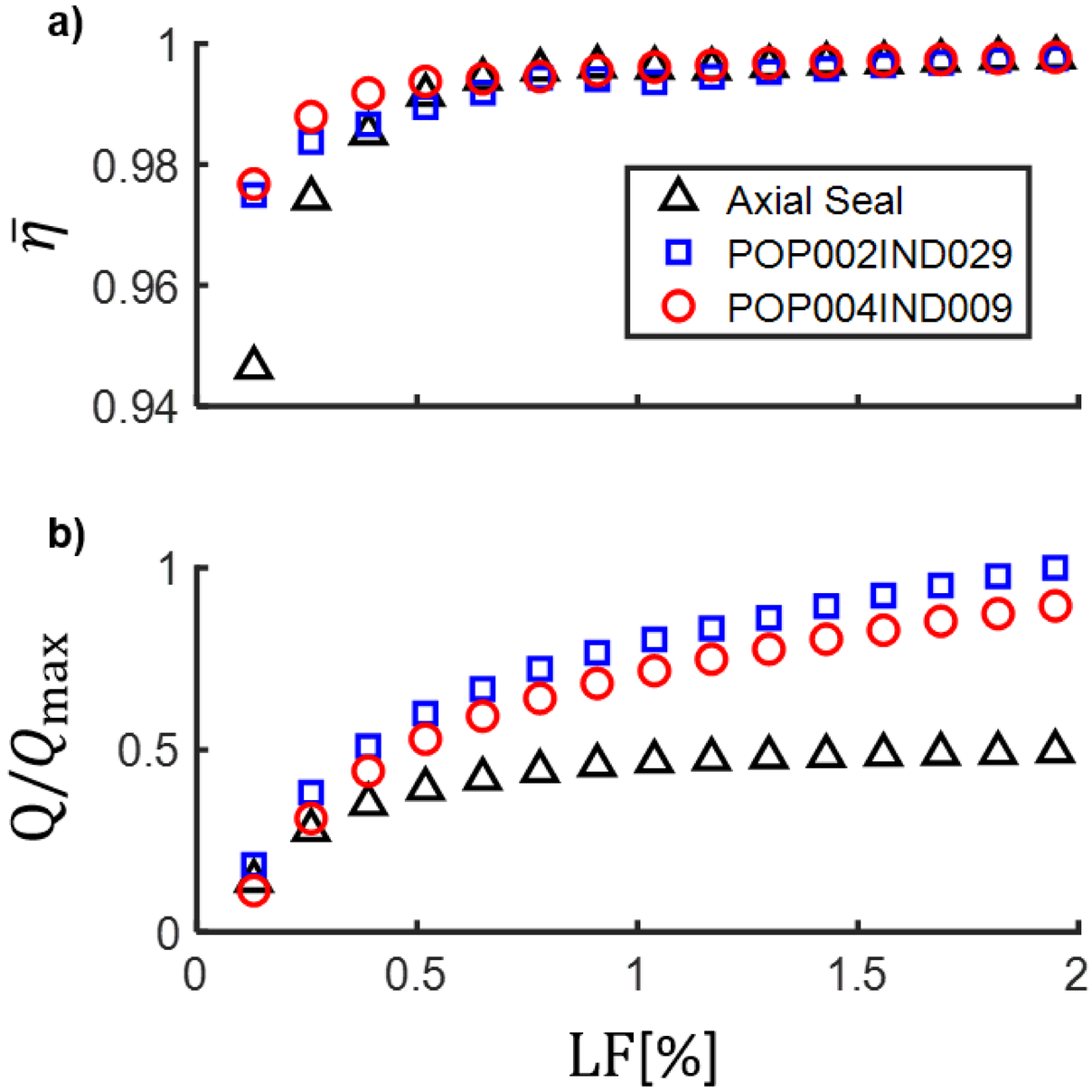




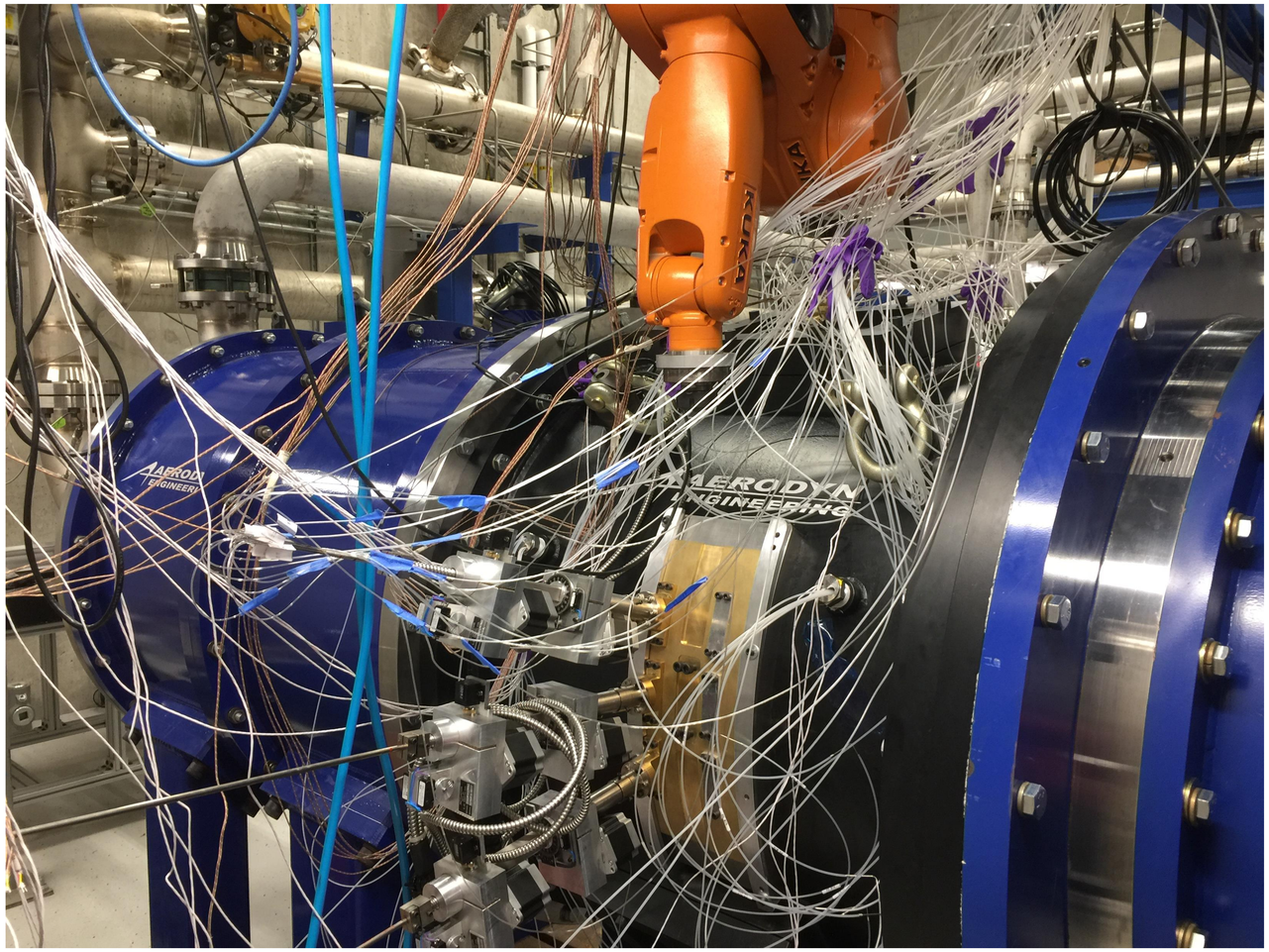
b)

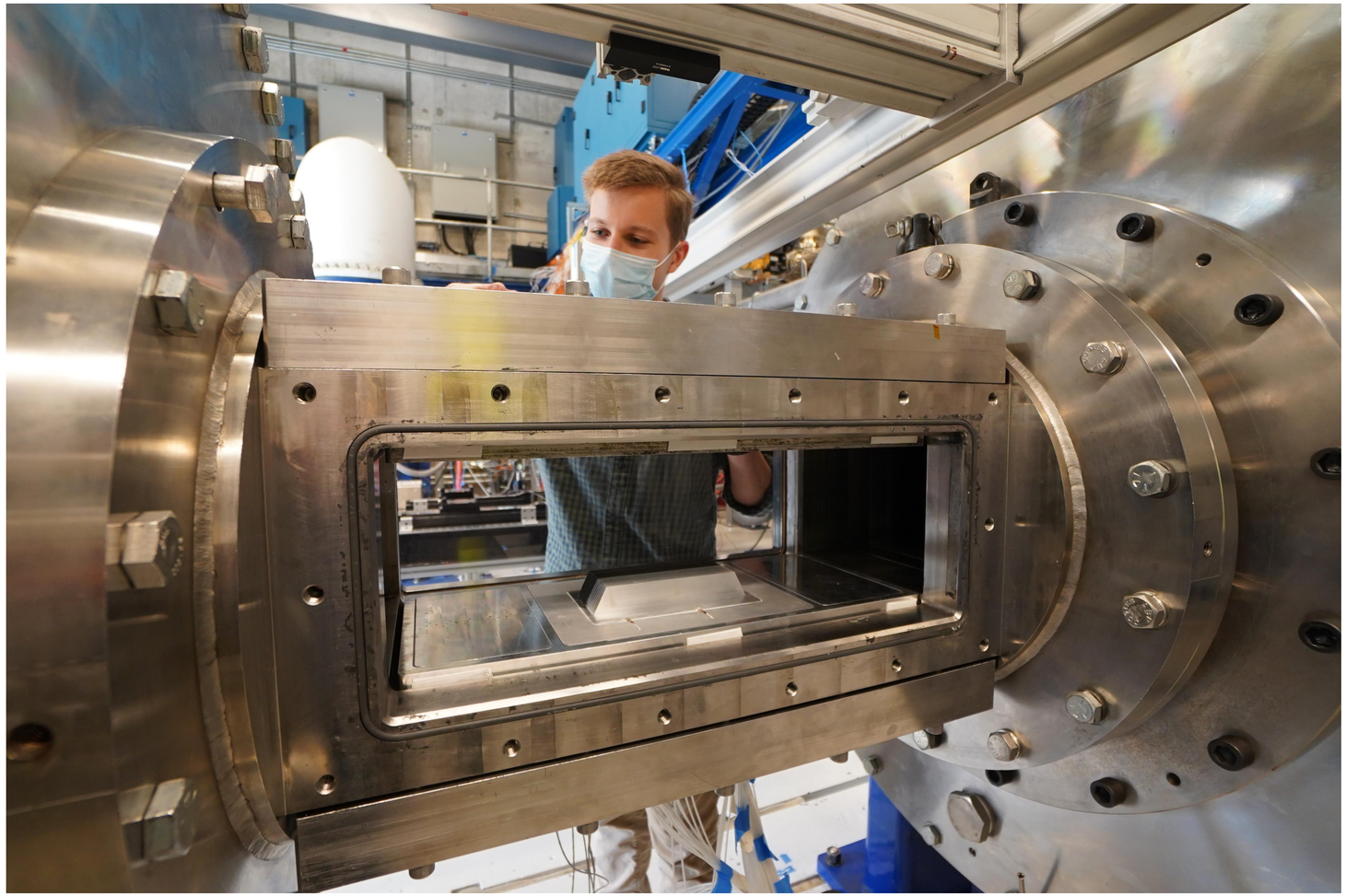
		E LF	% CHANGE AVG. HF
			2.9619
POP004IND009	-43.034		-11.536
POP002IND032	-59.094		-25.443
POP002IND029	-61.257		-38.083


no-slip, isothermal,
stationary walls
no-slip, isothermal,
stationary walls
periodic walls
pressure outlet
pressure inlet
no-slip, isothermal,
rotating walls
mass flow inlet



$$\eta(r) = \frac{T_{o,passage,in} - T_{o,cavity}(r)}{T_{o,passage,in} - T_{o,cavity,in}}$$


KUKA
AERODYN
ENGINEERING



Thank You

QUESTIONS?

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