Turbine research at Purdue from Innovation to Maturity

petal
Purdue Experimental
Turbine Aerothermal Lab

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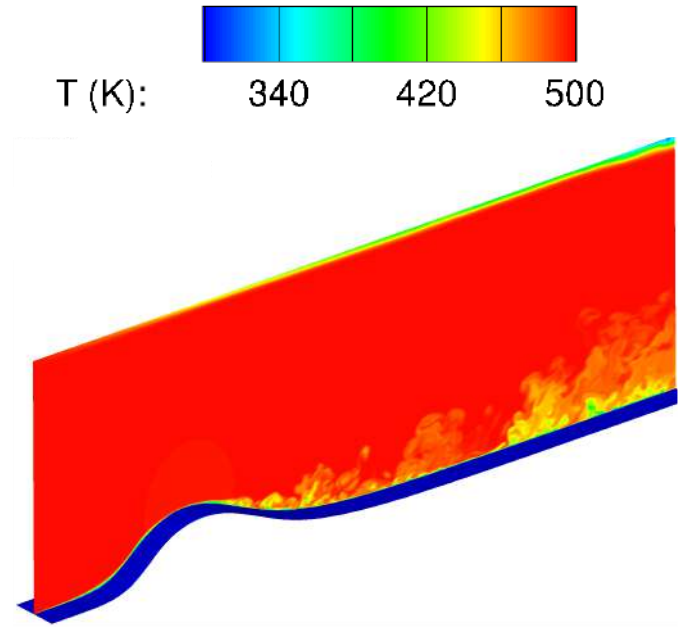
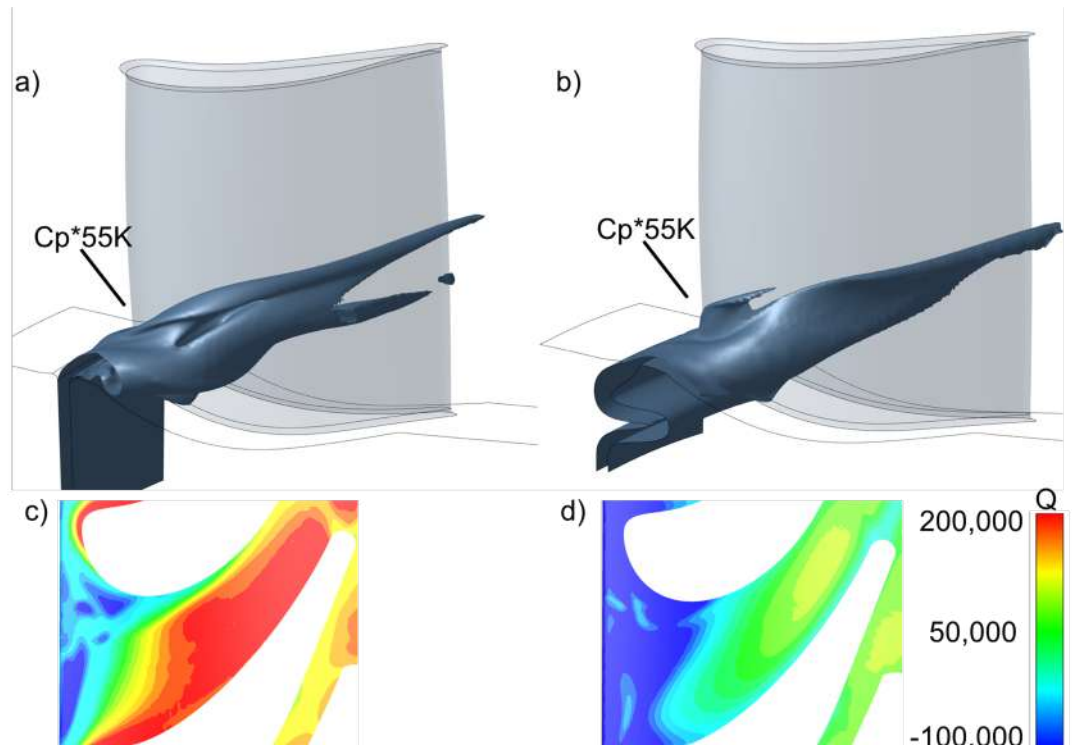
Turbine challenges

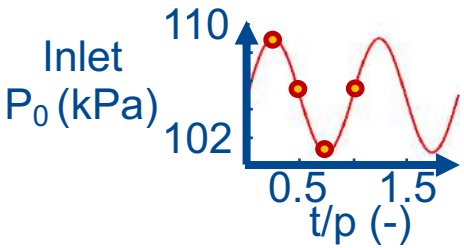
fundamental



applied

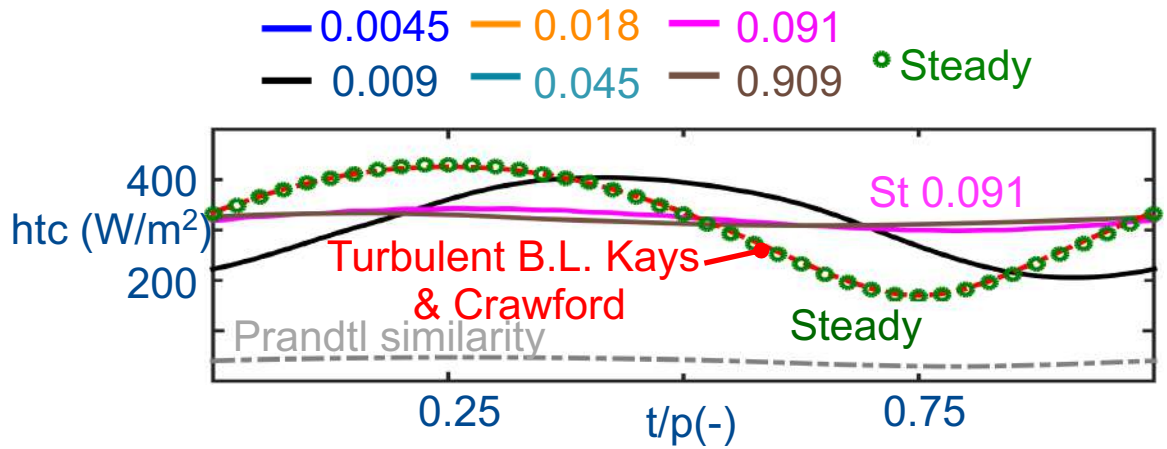


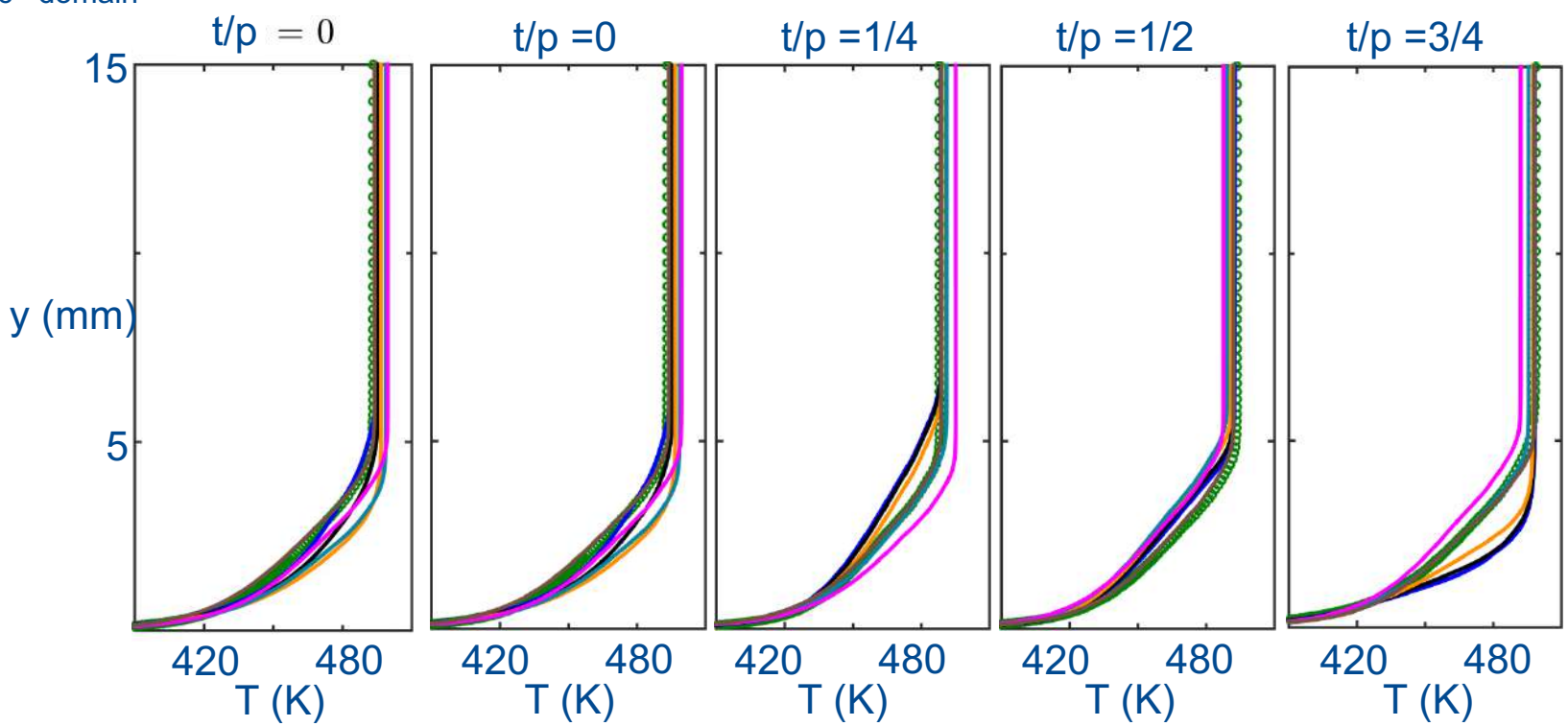
Boundary Layer Separation & Control



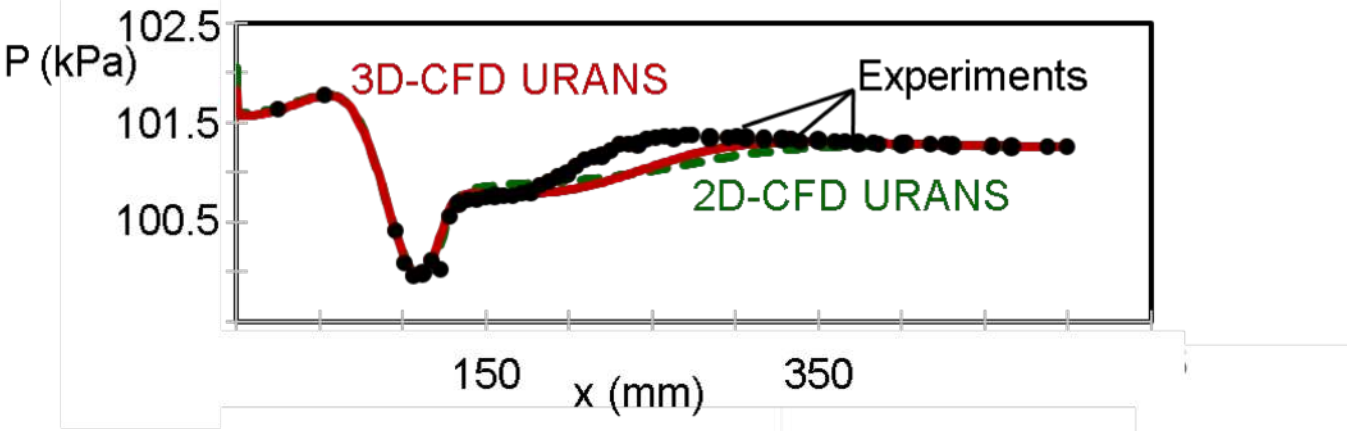
$f_{domain} = \frac{L_{domain}}{c + \overline{xv}}$

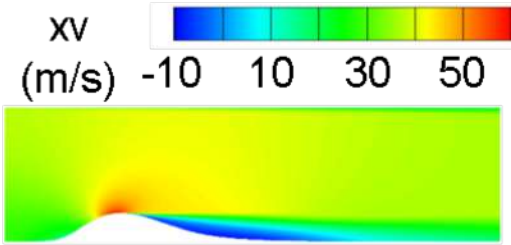
$St_{domain} = f_{exc}/f_{domain}$

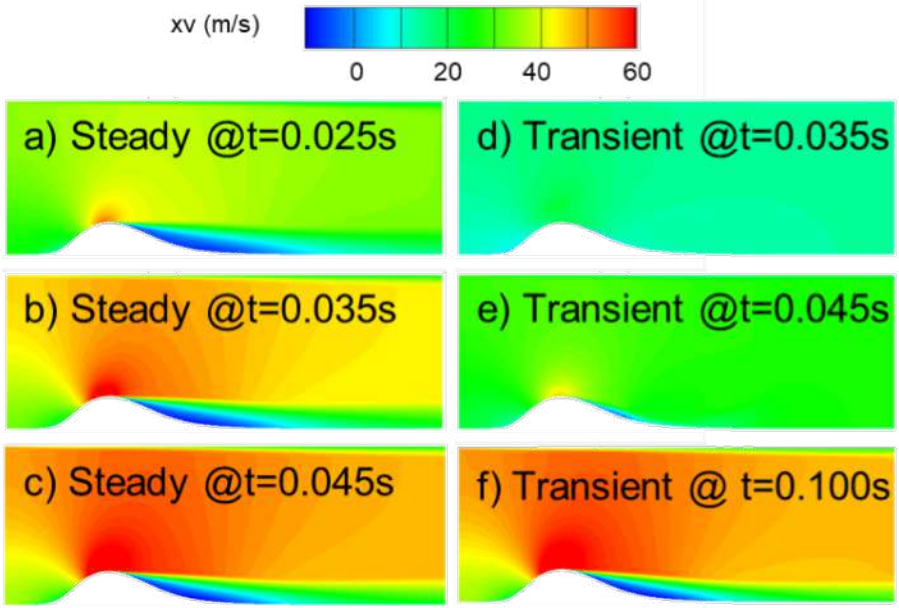




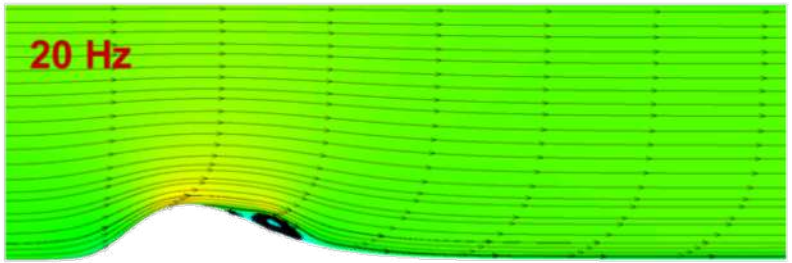
Boundary Layer Separation & Control



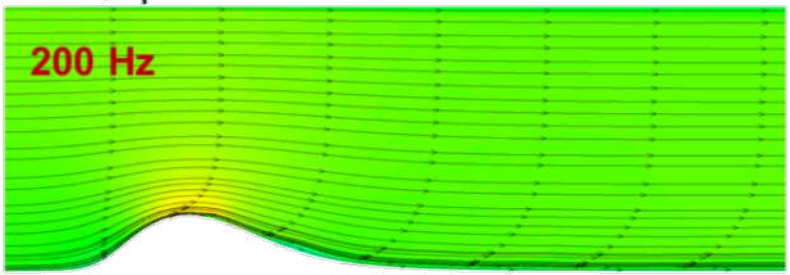




Mean flow variations effect on boundary layer detachment



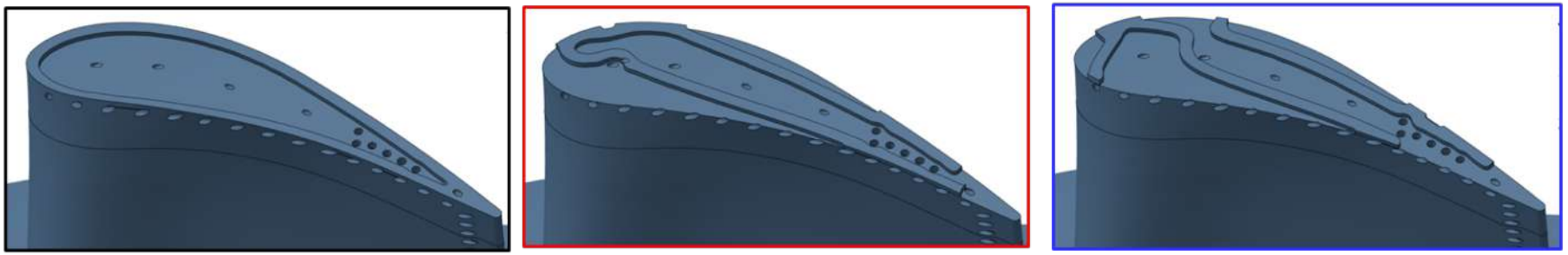
	No inj.	10 Hz	20 Hz	50 Hz	100 Hz	200 Hz	500 Hz
$\frac{P_0 loss}{P_{dyn}}$	6.06%	2.64%	2.57%	2.28%	2.14%	1.99%	2.02%

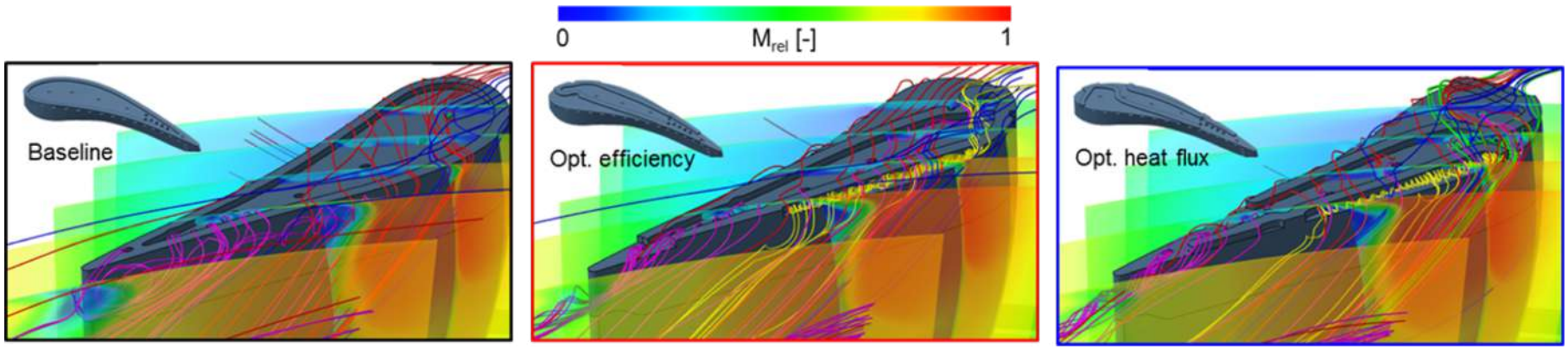


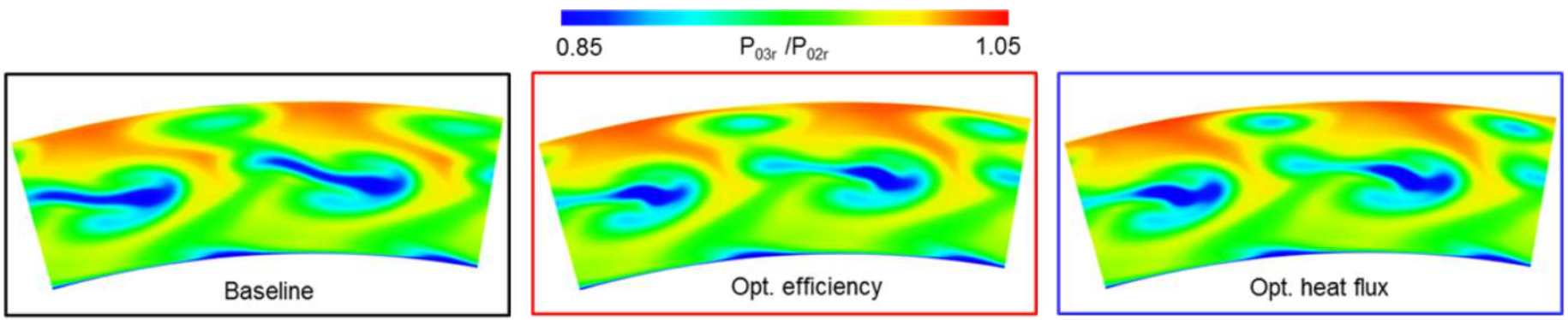
Optimum frequency actuation to prevent flow separation

Turbine tip optimization

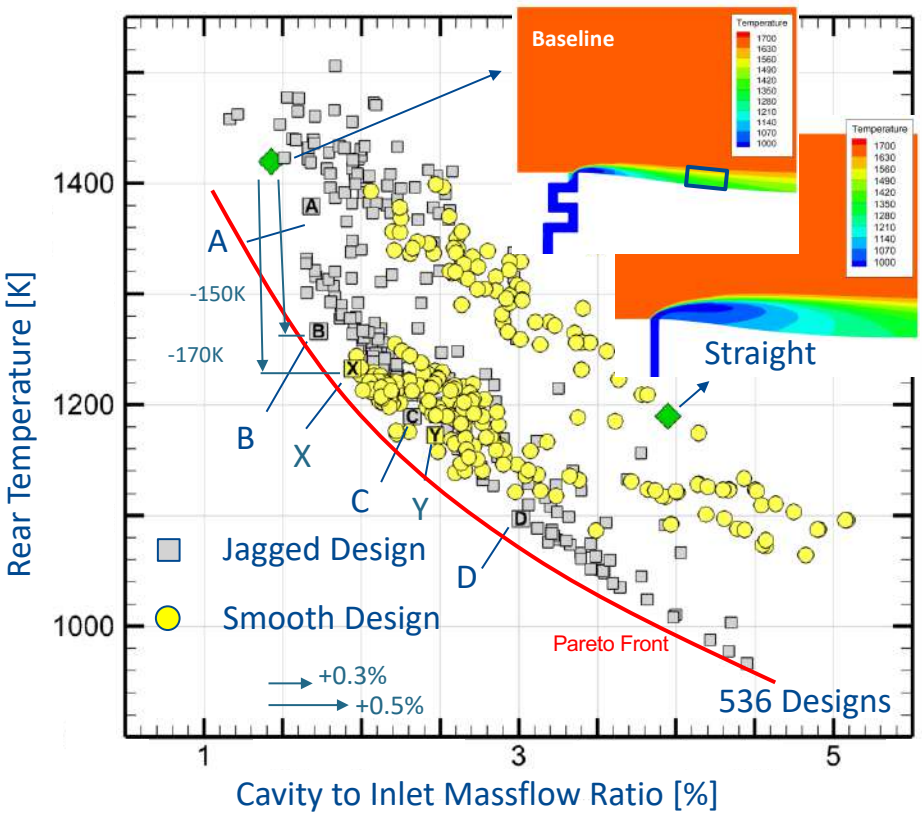
Baseline | Opt. efficiency | Opt. heat flux

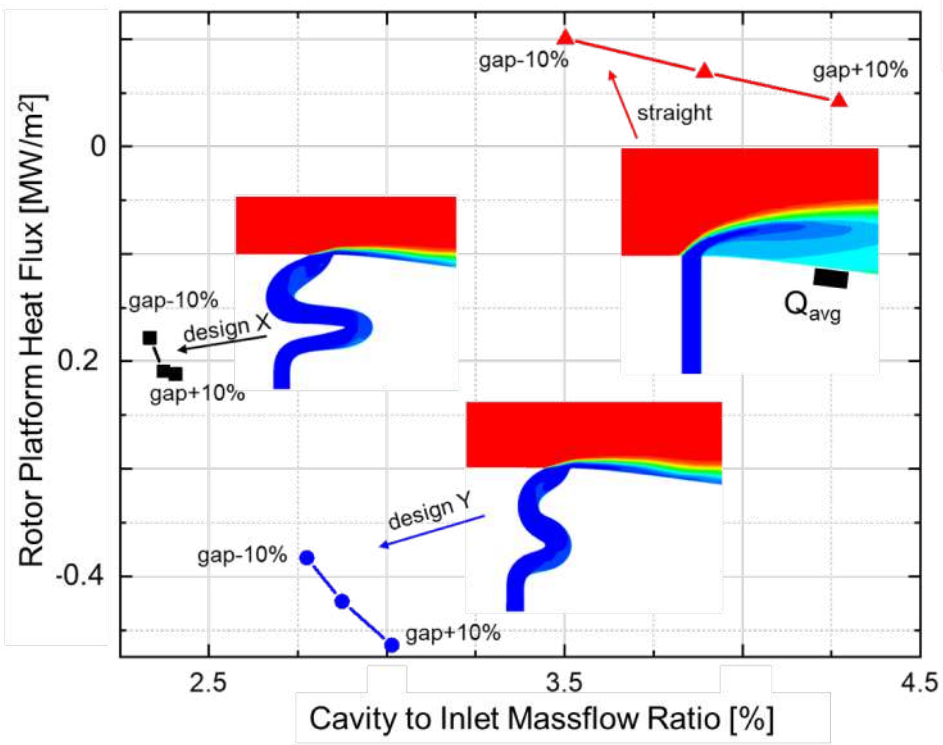






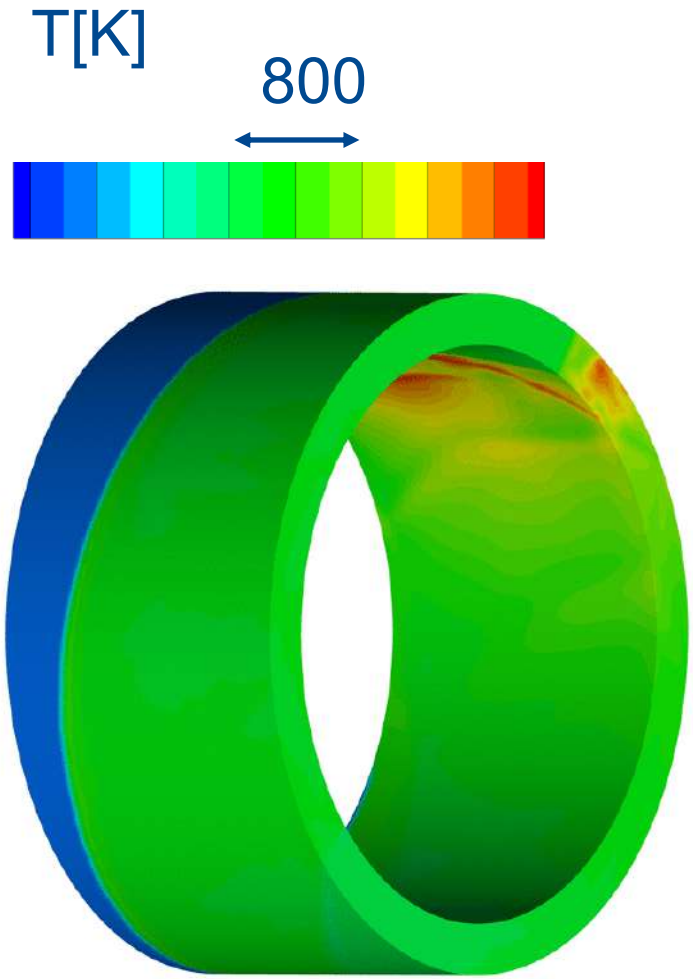
Stator rim – rotor platform cavity

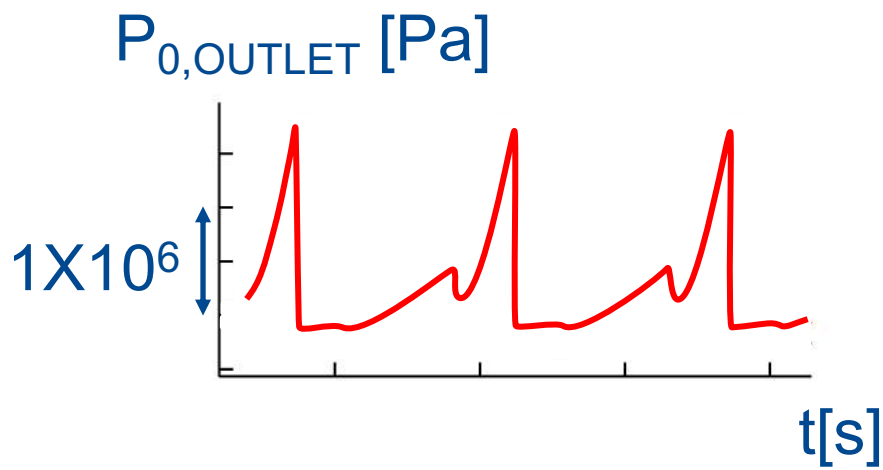


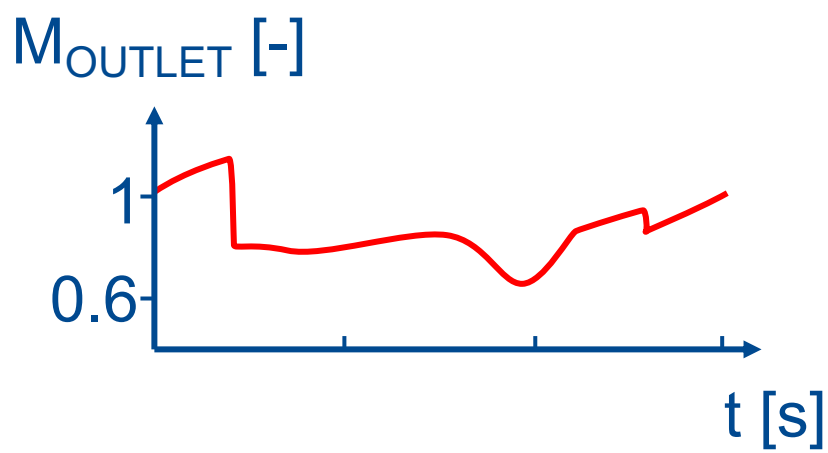


Turbines for Pressure gain combustors

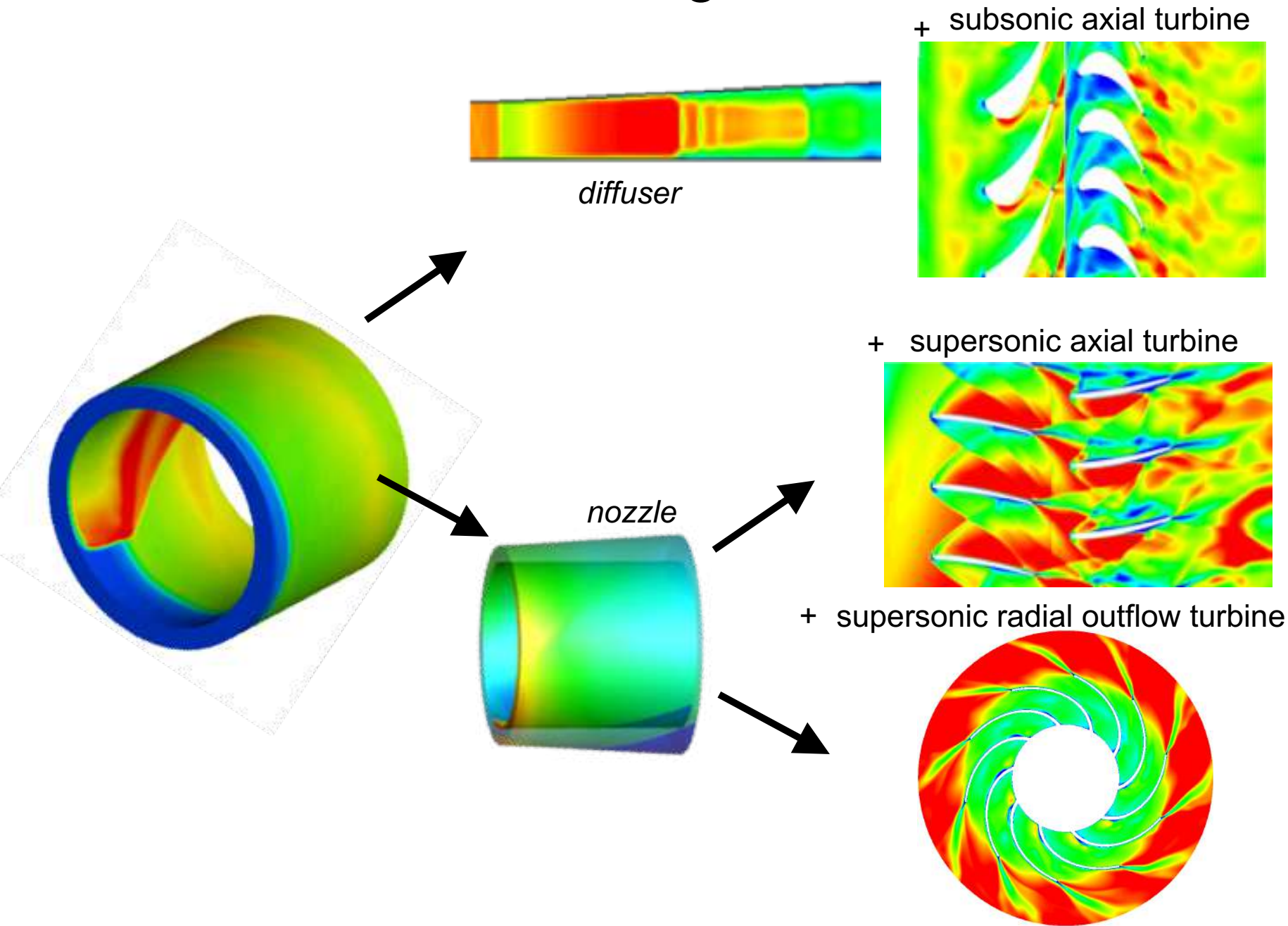
Outlet fluctuations behind combustor up to 100 %







Turbines for Pressure gain combustors

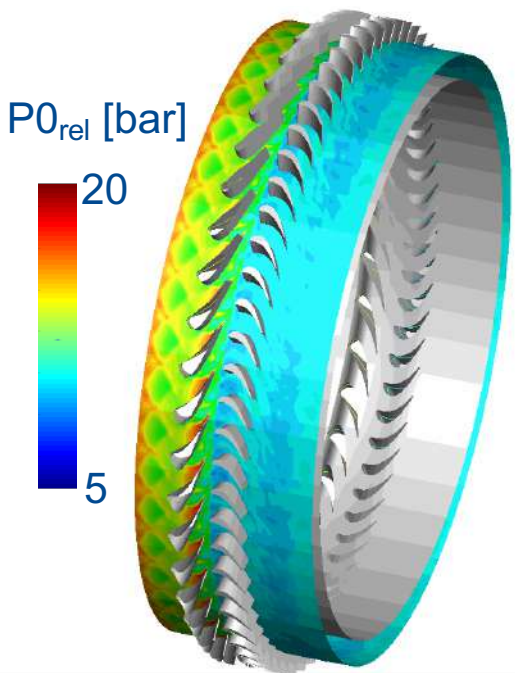


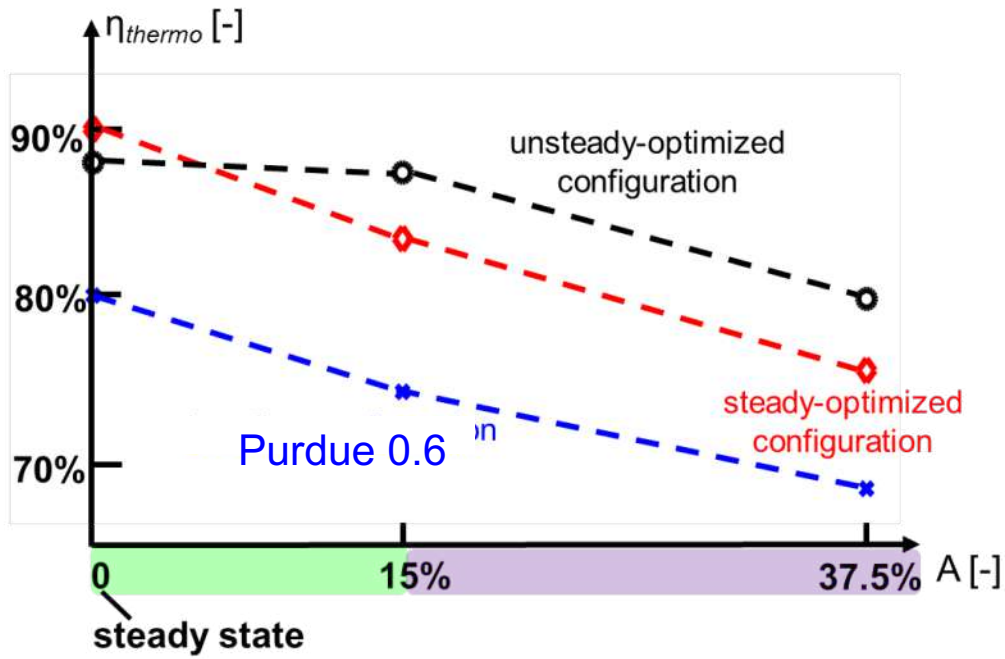
Turbines for Pressure gain combustors
full unsteady analysis

Instantaneous mass flow averaged → *Time averaged of mass flow averaged* → *Turbine efficiency:*

$$\bar{T}_{01}(t) = \frac{\sum_{i=1}^{n} T_{01}(t)\rho_i\left|\overrightarrow{V_{ax\_i}} \cdot \vec{S_i}\right|}{\sum_{i=1}^{n} \rho_i\left|\overrightarrow{V_{ax\_i}} \cdot \vec{S_i}\right|} \qquad T_{01} = \frac{\int_0^t m(t)\bar{T}_{01}(t)dt}{\int_0^t m(t)dt} \qquad \eta_{thermo} = \frac{T_{01} - T_{03}}{T_{01} - T_{03s}}$$

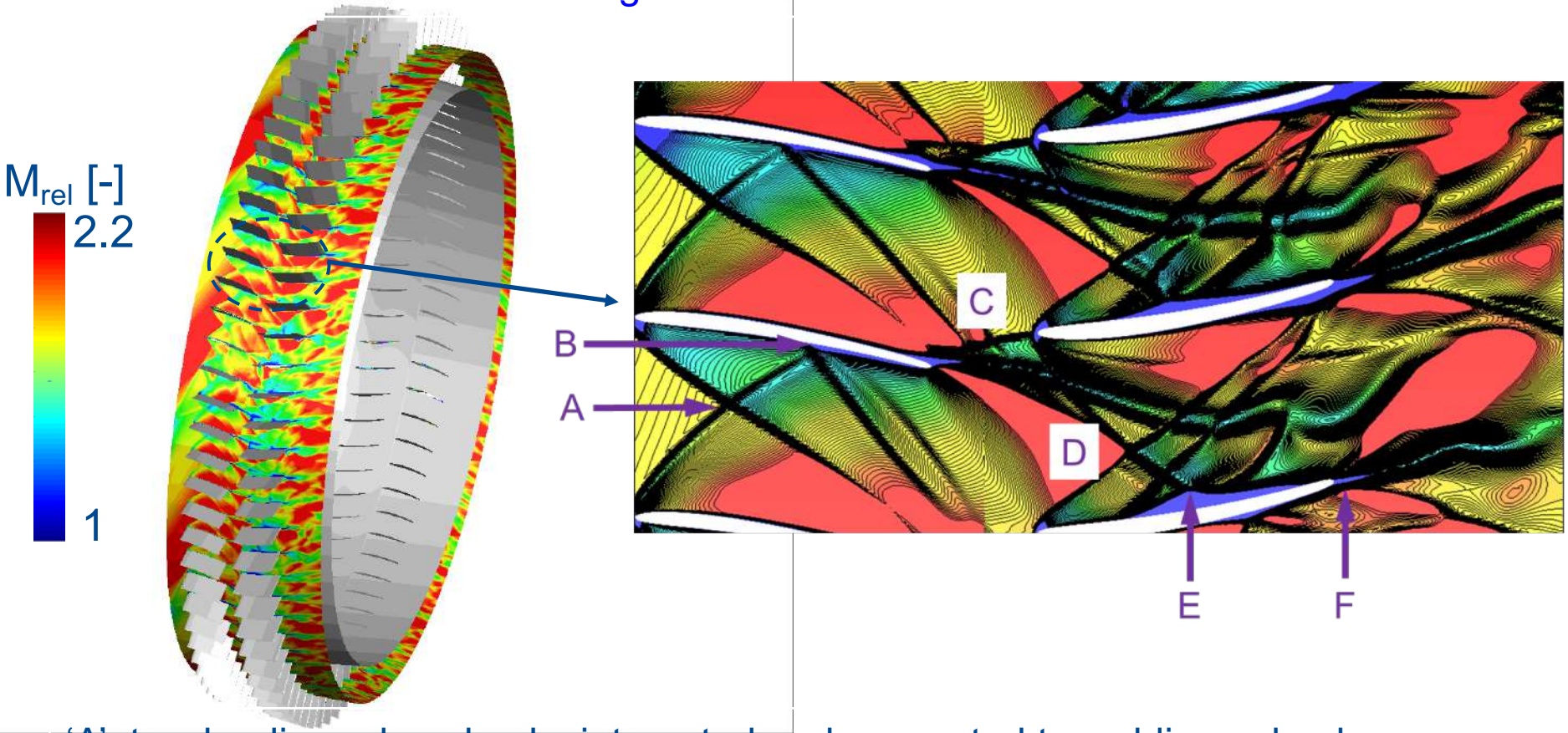
	'Purdue 0.6'	steady-optimized configuration	unsteady-optimized configuration
Full unsteady ($\bar{f}$ =0.23, A=37.5%)	68.4%	75.5%	79.8%





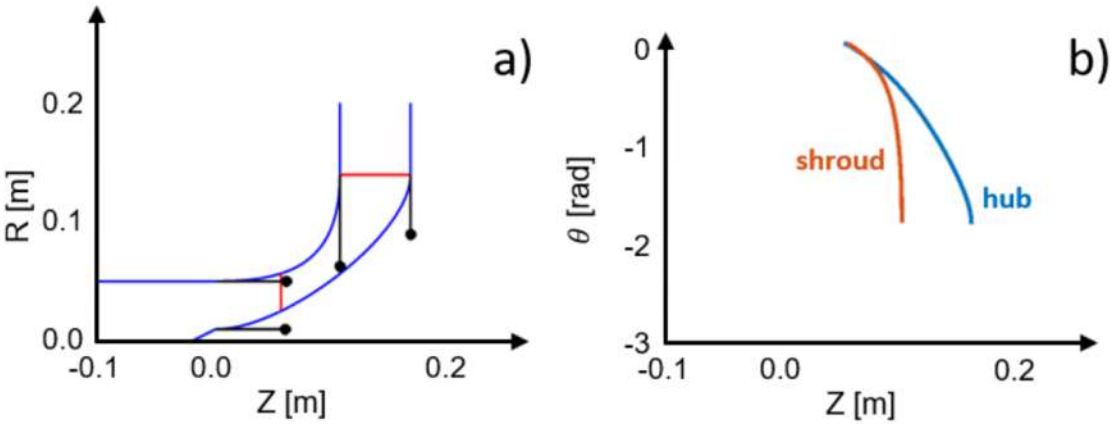
Turbines for Pressure gain combustors

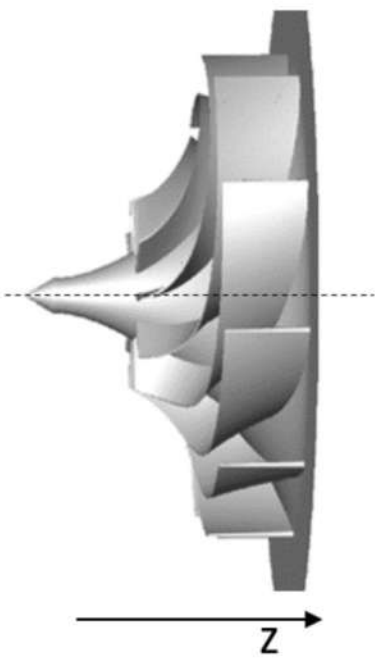
- 3D mesh: 31million; 25 TB data
- 360 hrs for 1 URANS turbine stage on 30 cores

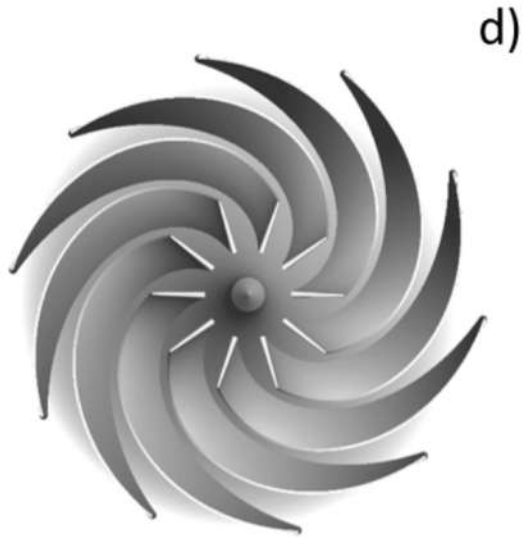


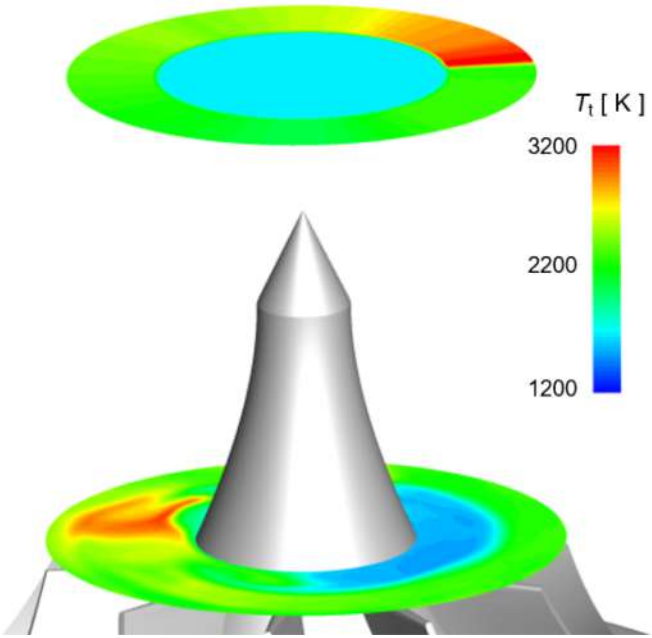
'A': two leading edge shocks interacted and generated two oblique shocks
'B': weak shock boundary layer interaction
'C': reflected shocks from 'B' interacted with the stator trailing edge shock
'D': multiple shocks interacted
'E': strong shock boundary layer interaction which led to a low subsonic pocket
'F': rotor trailing edge shock

Turbines for Pressure gain combustors



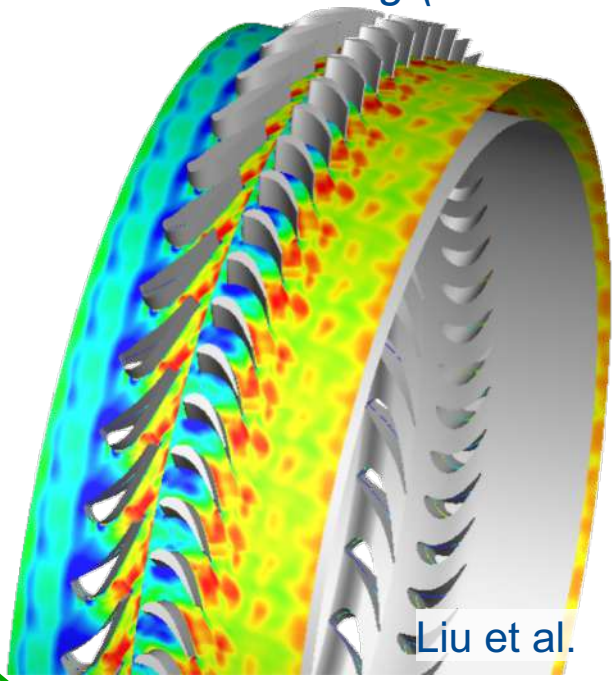






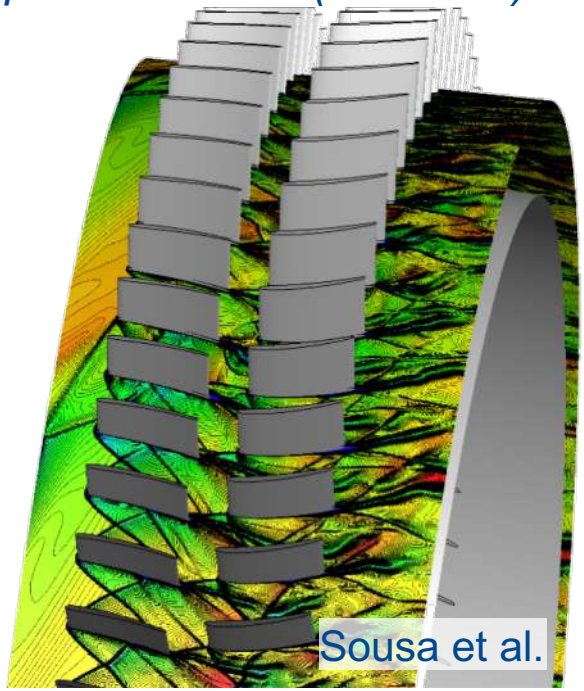
Turbines for Pressure gain combustors

end wall contouring (<Mach 1)



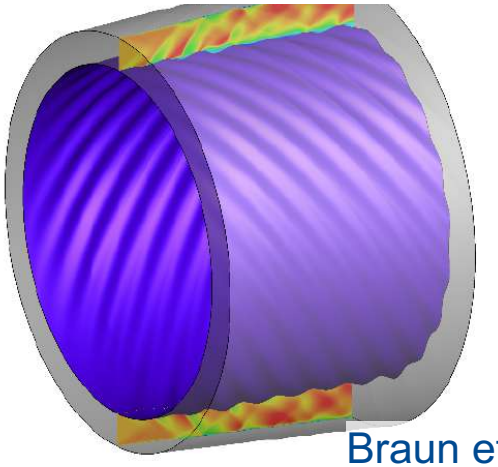
Liu et al.

supersonic axial (>Mach 1)



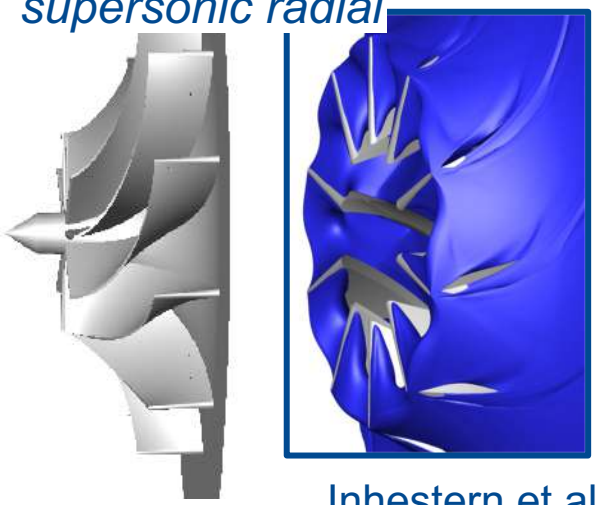
Sousa et al.

axial bladeless turbine



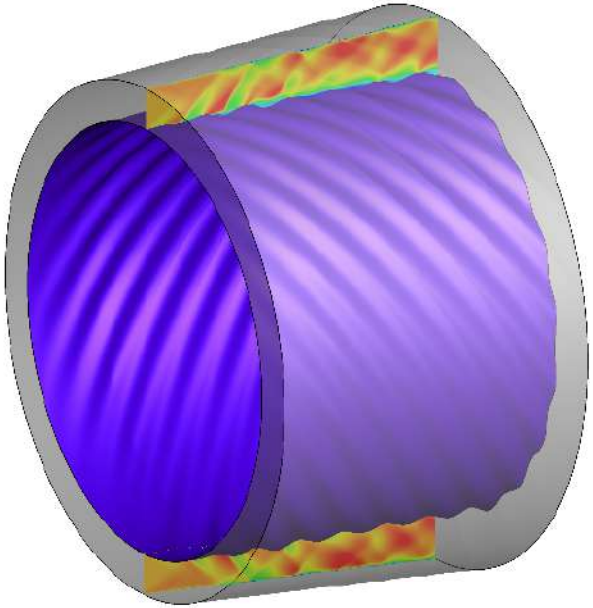
Braun et al.

supersonic radial

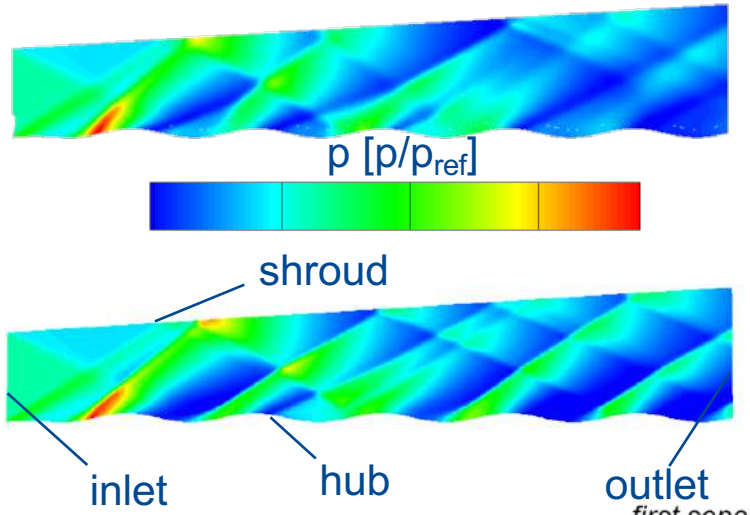


Inhestern et al.

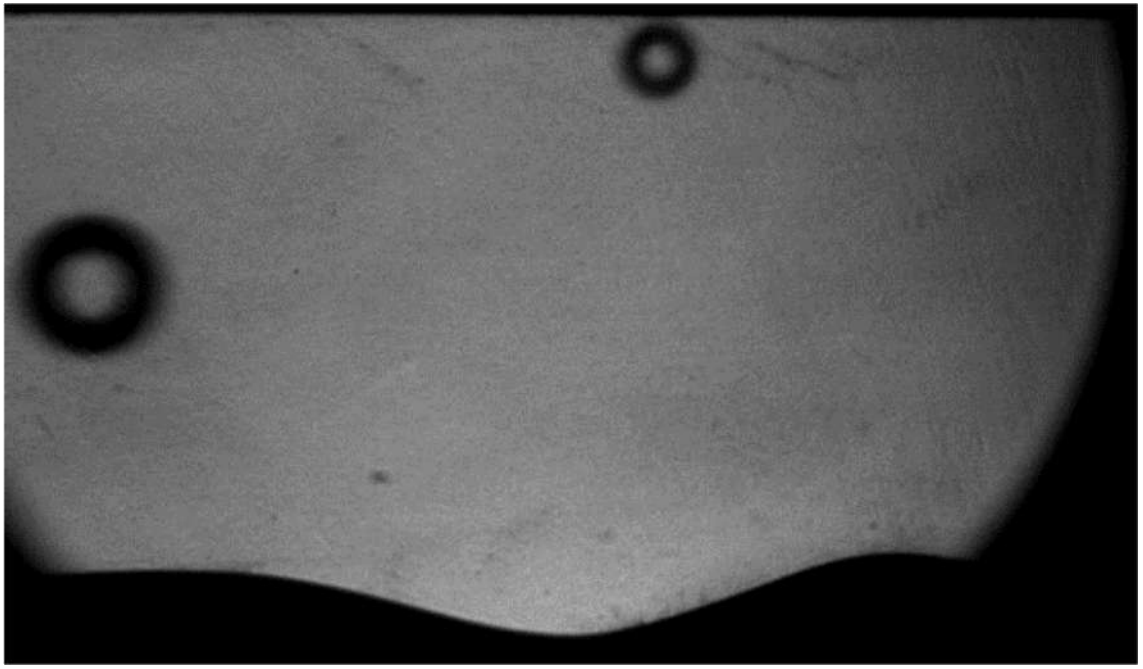
Turbines for Pressure gain combustors

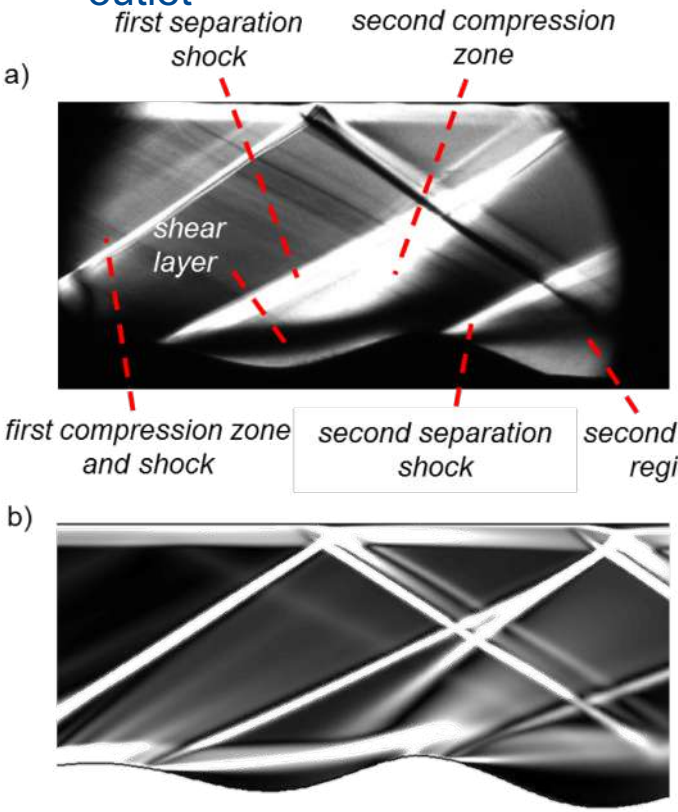


tangential cut

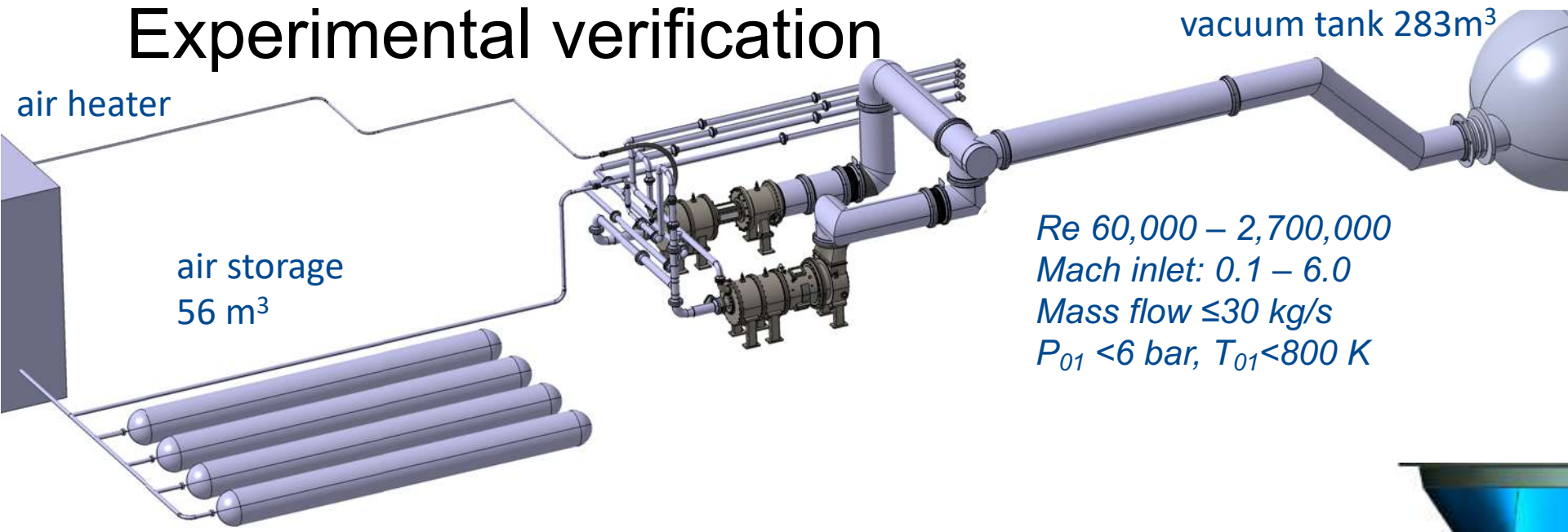


2D simulation



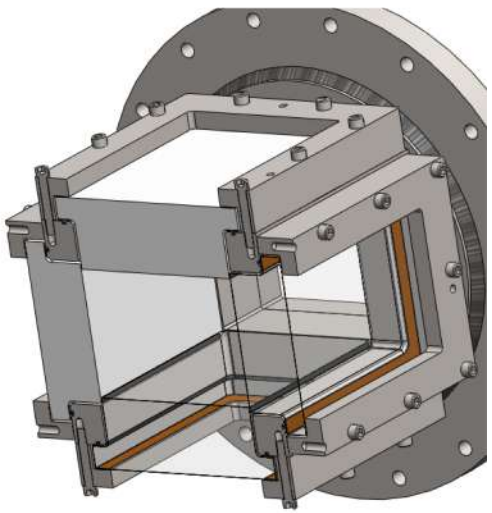


Experimental verification



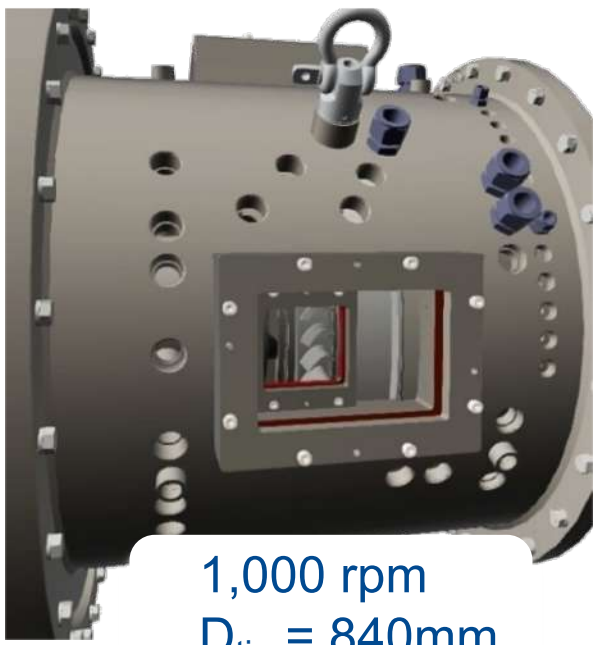
Re 60,000 – 2,700,000
Mach inlet: 0.1 – 6.0
Mass flow ≤30 kg/s
P_{01} <6 bar, T_{01}<800 K

TRL: 1-2 **LEAF**



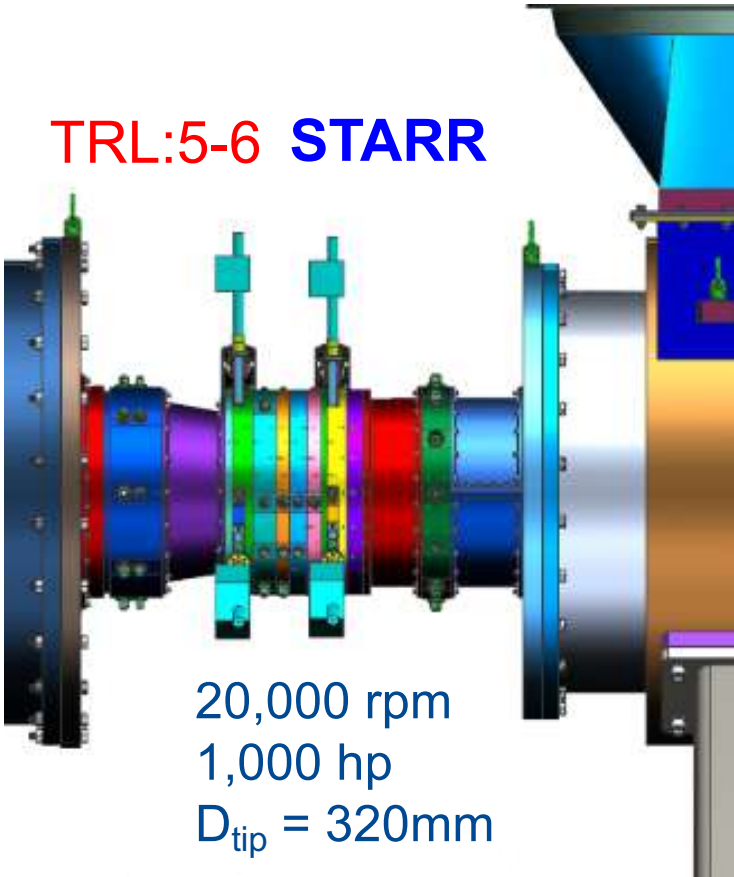
230 × 170 mm

TRL:3-4 **BRASTA**



1,000 rpm
D_{tip} = 840mm

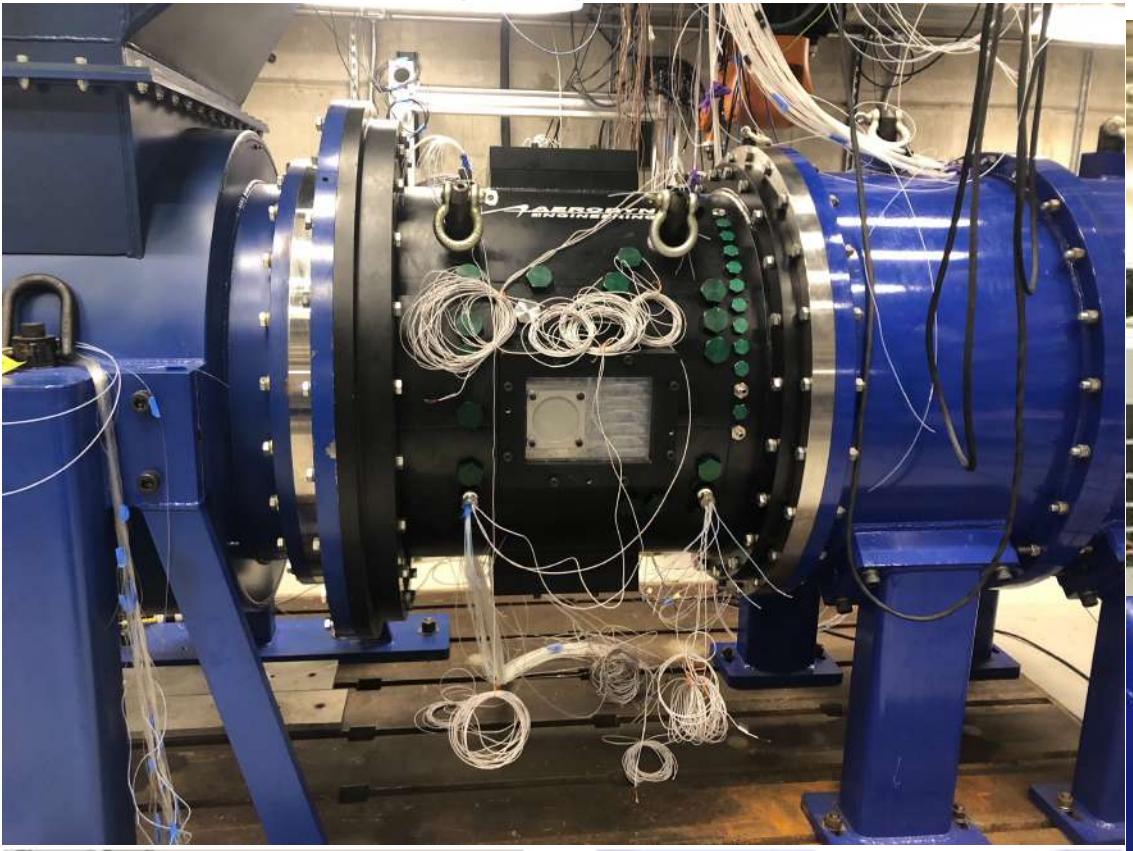
TRL:5-6 **STARR**

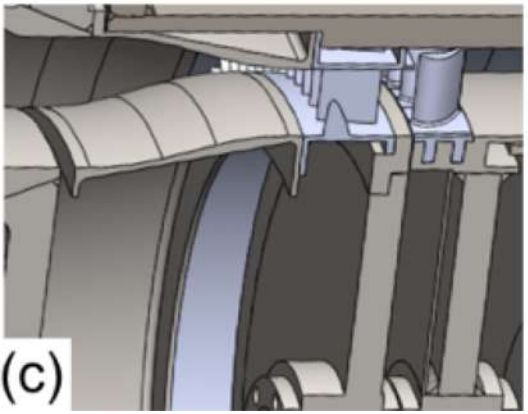


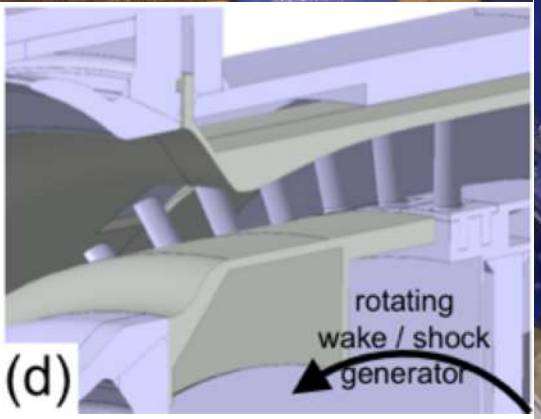
20,000 rpm
1,000 hp
D_{tip} = 320mm

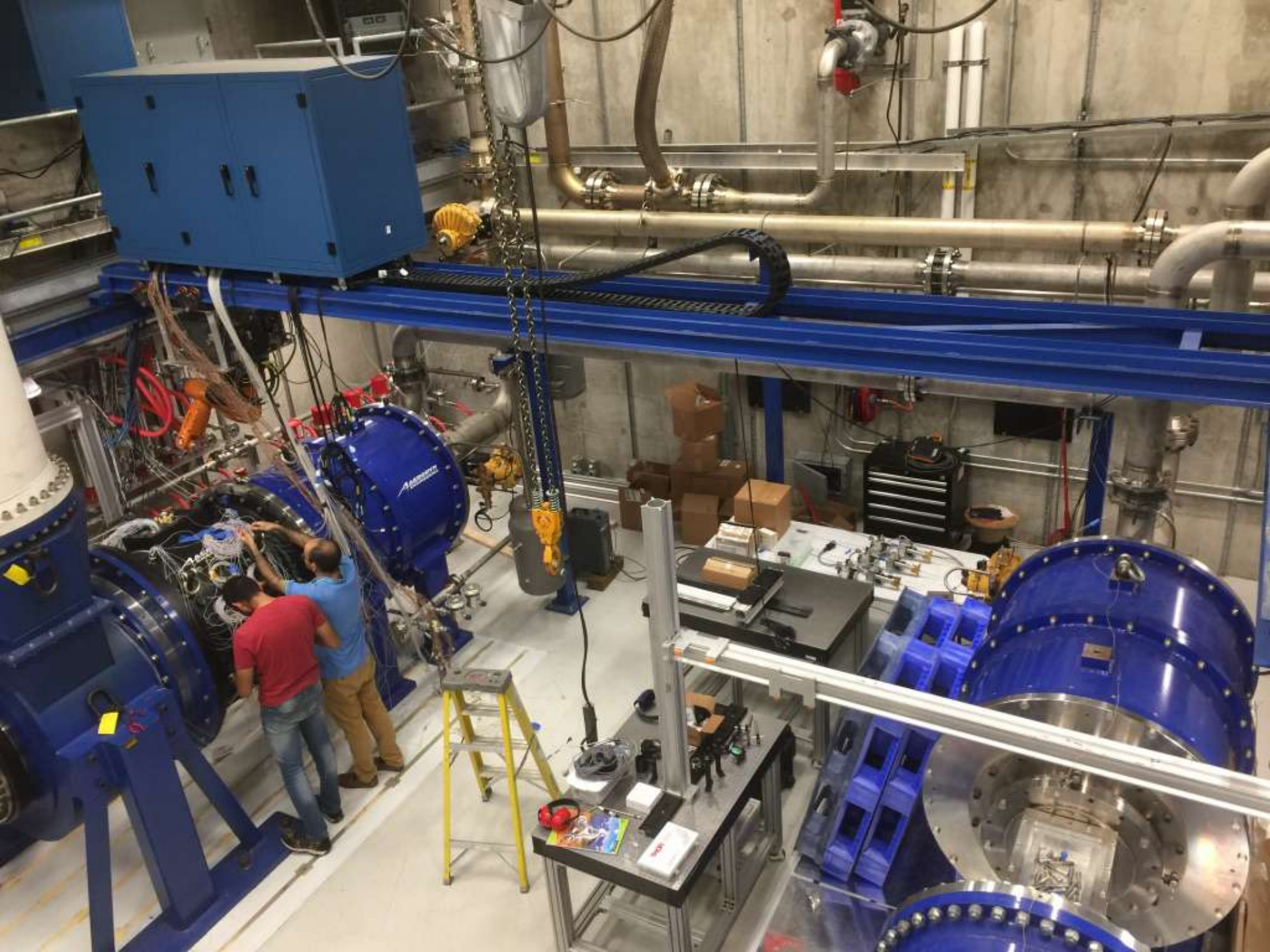
Experimental verification: Rigs

BRASTA - Big Rig for Aerothermal Stationary Turbine Analysis

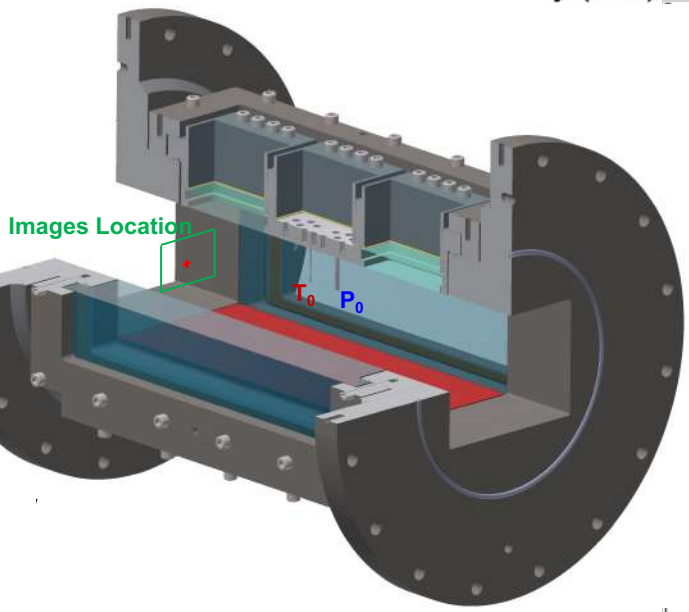


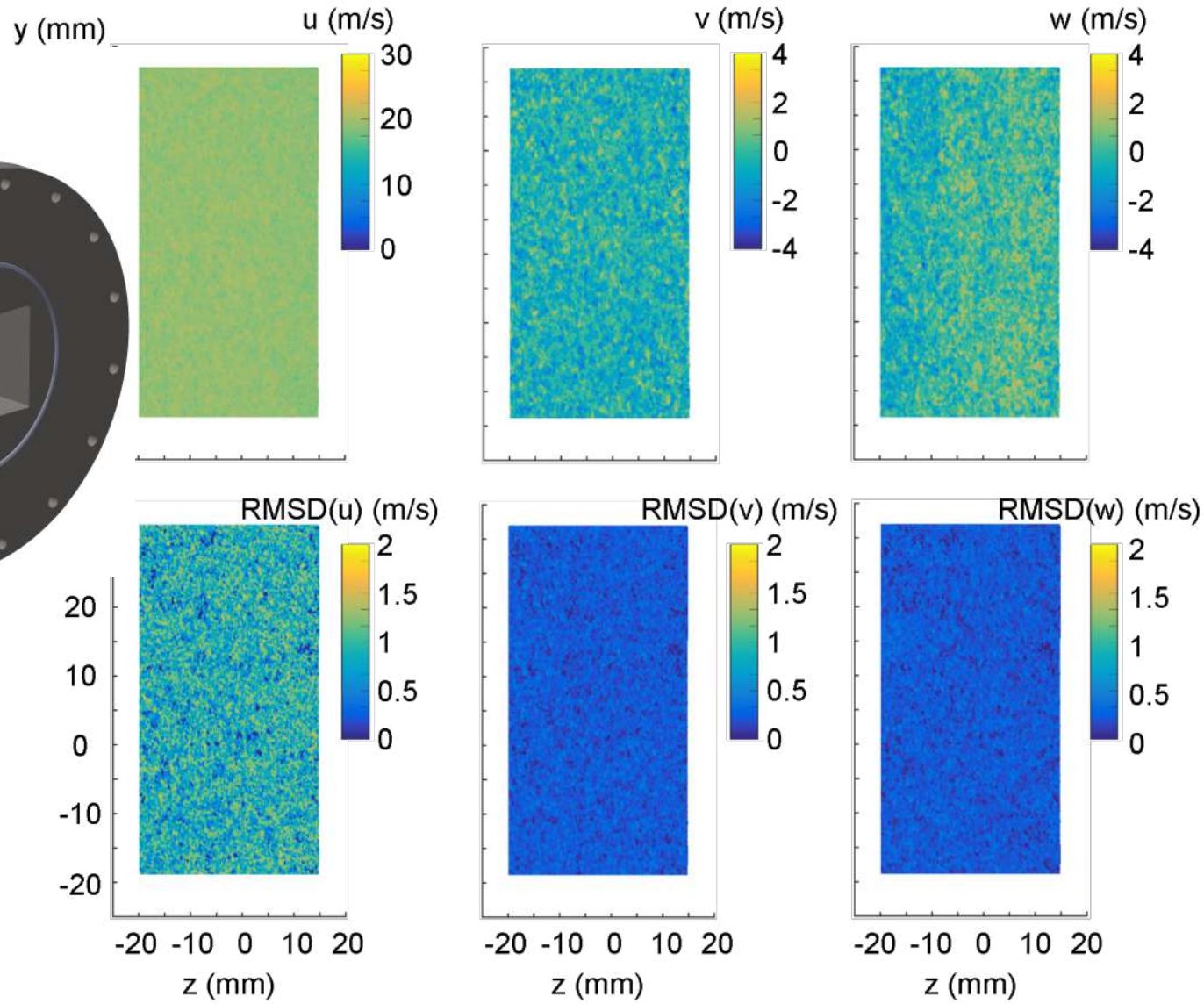






Experimental verification: Measurement tech.





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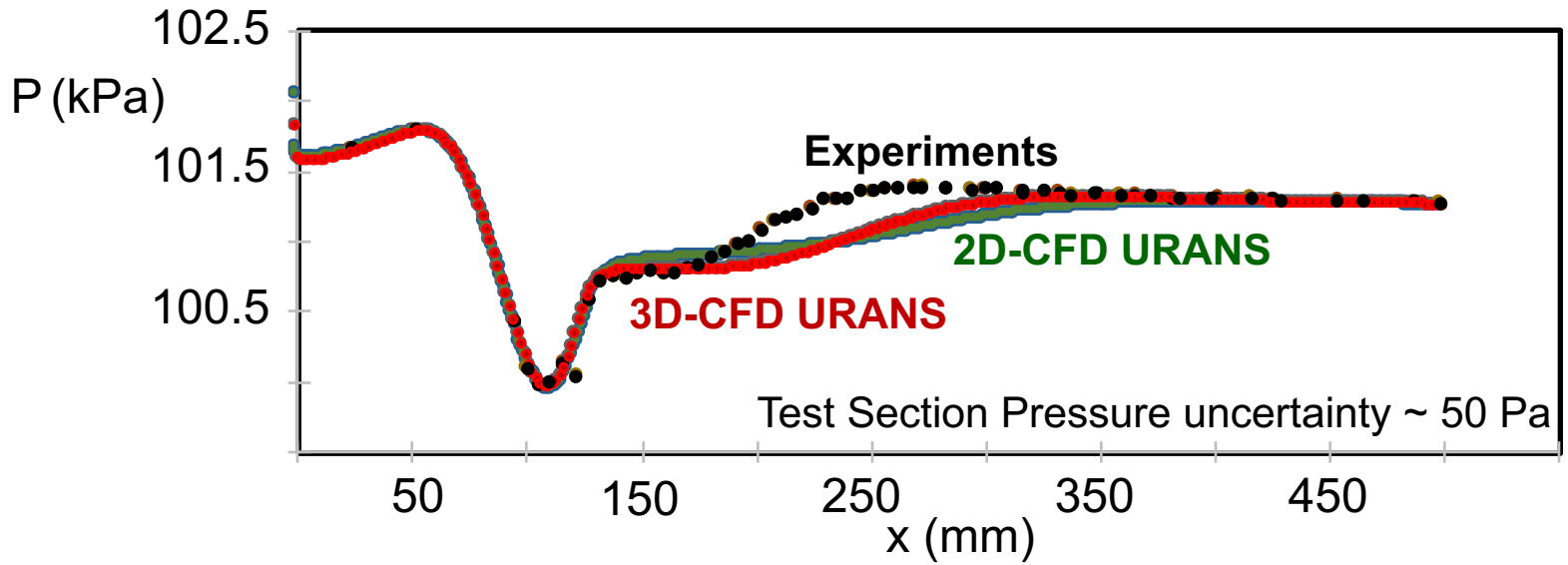
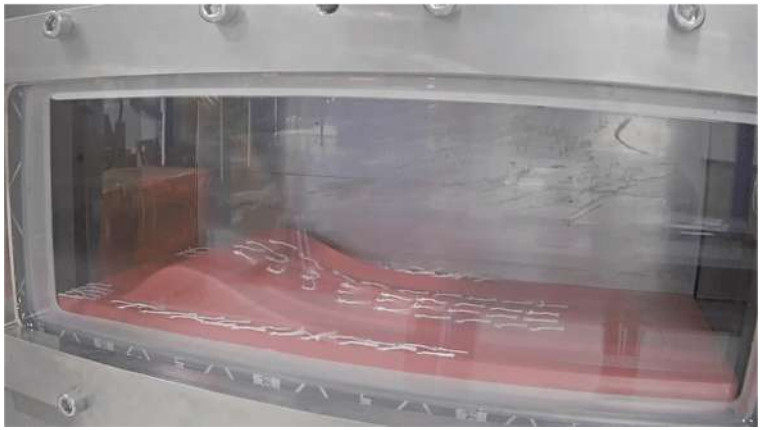
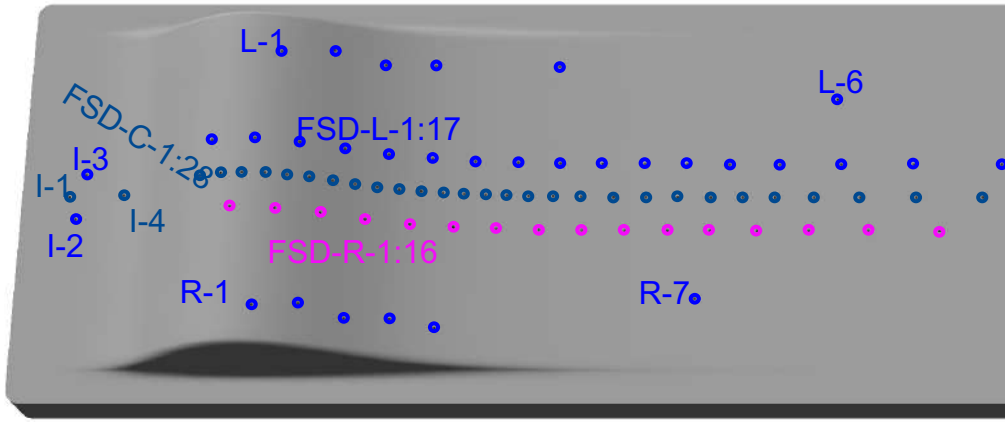




Static pressure tappings distribution



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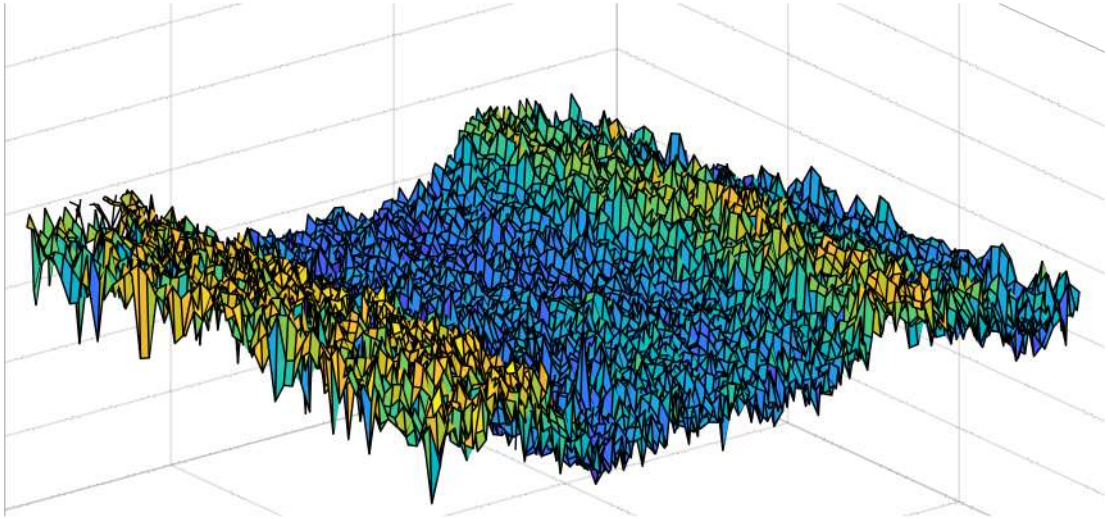

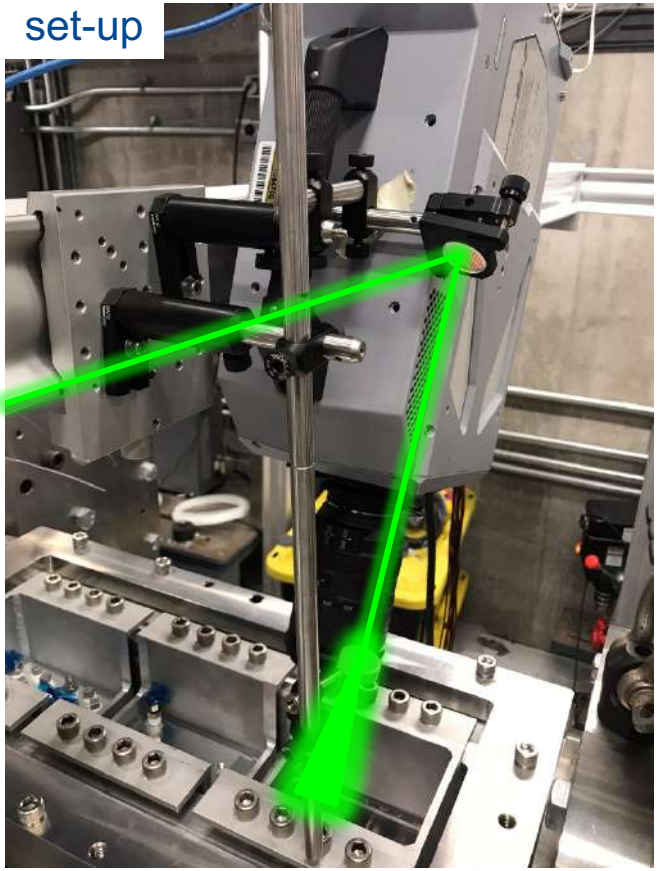

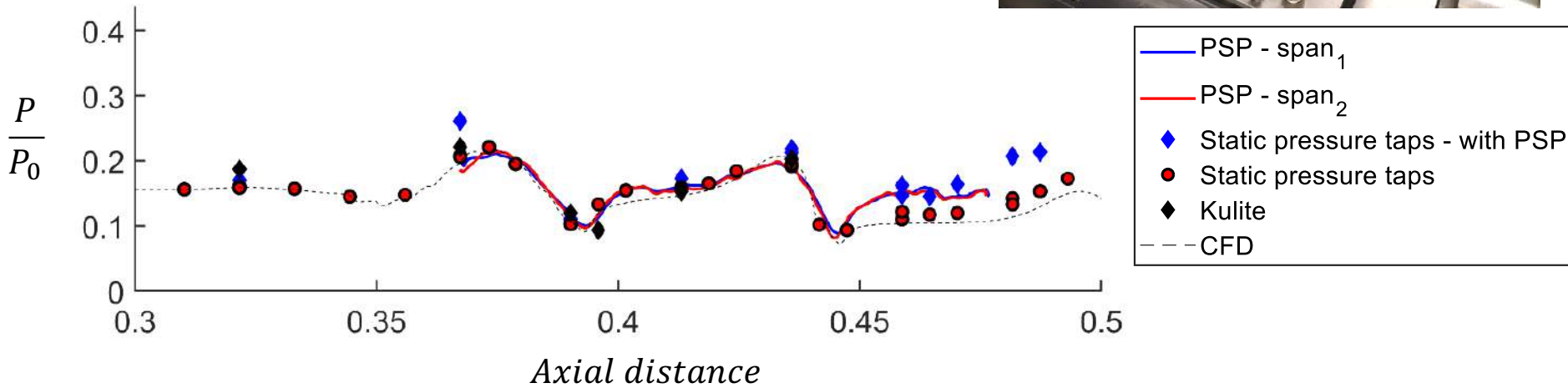

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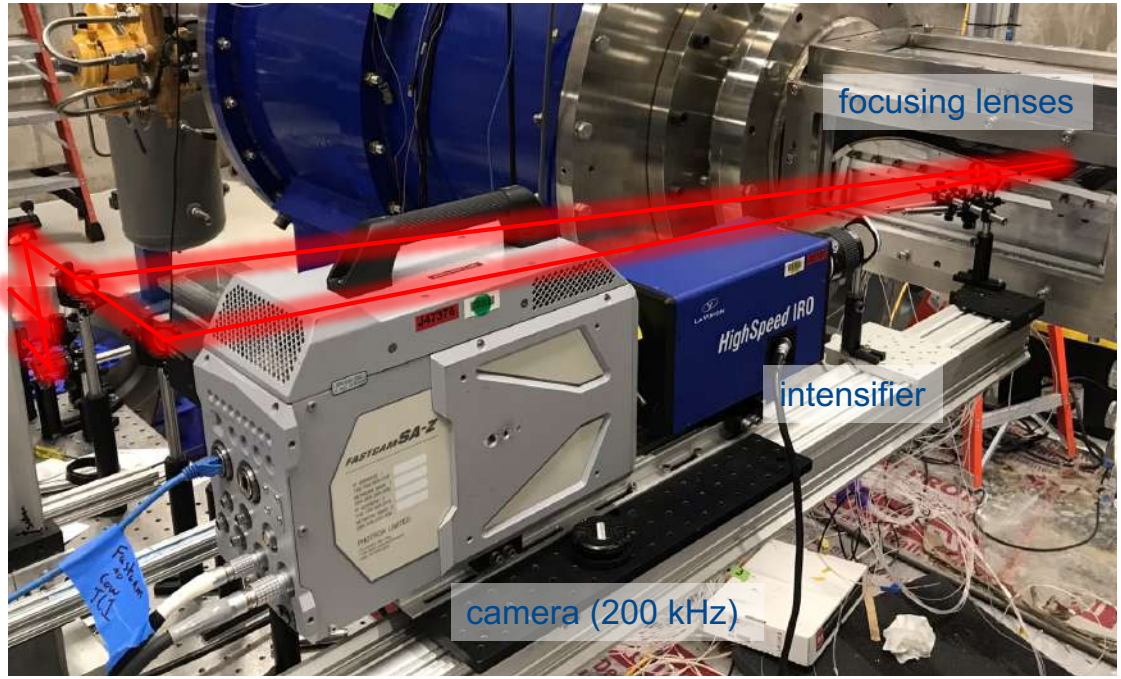
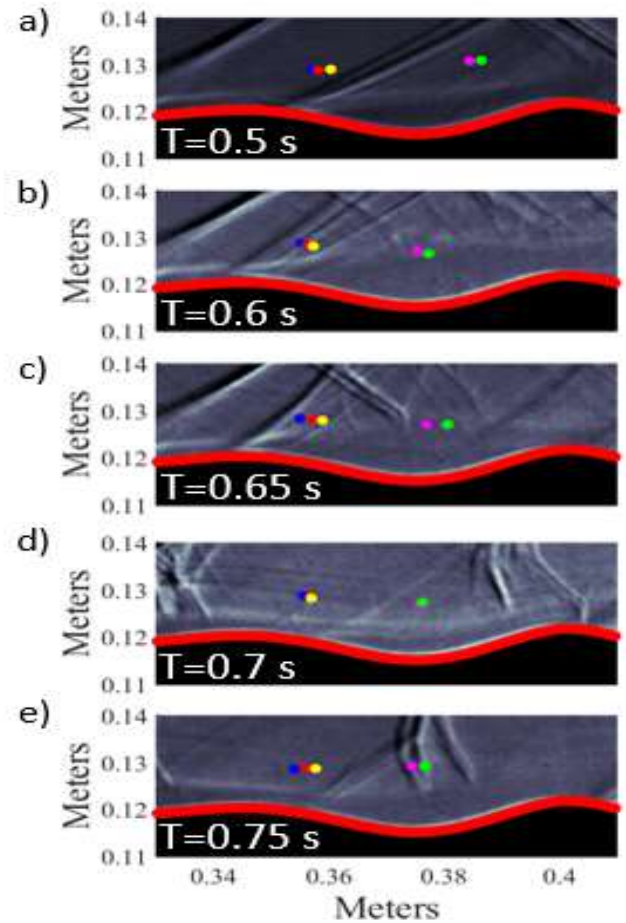
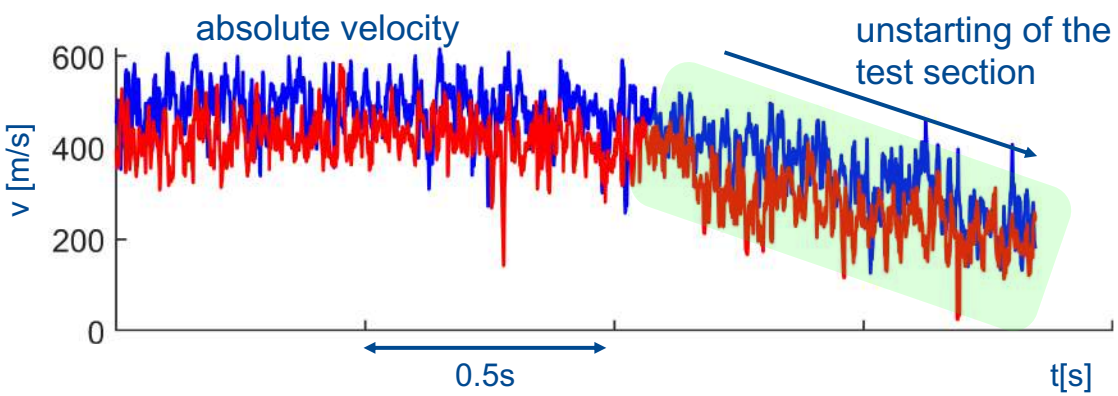
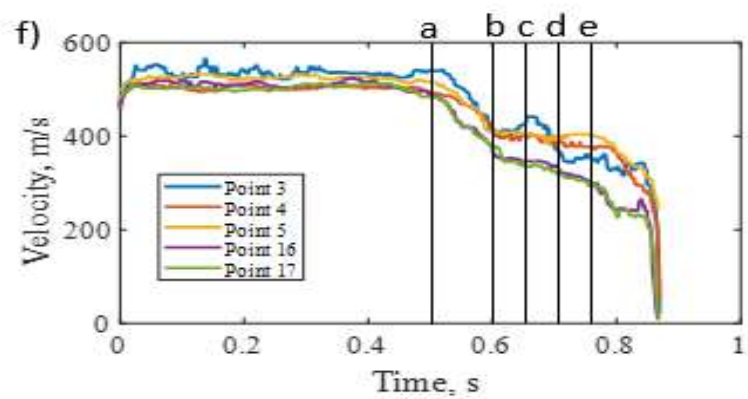


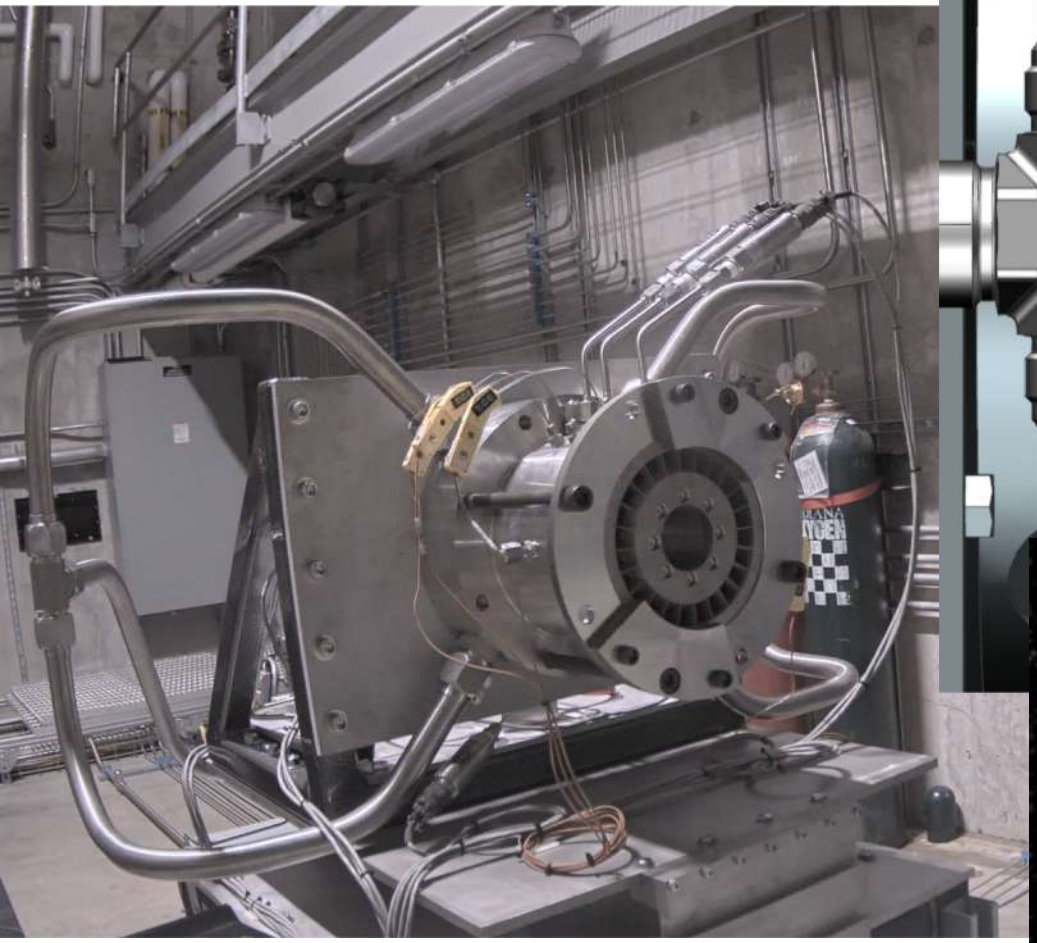


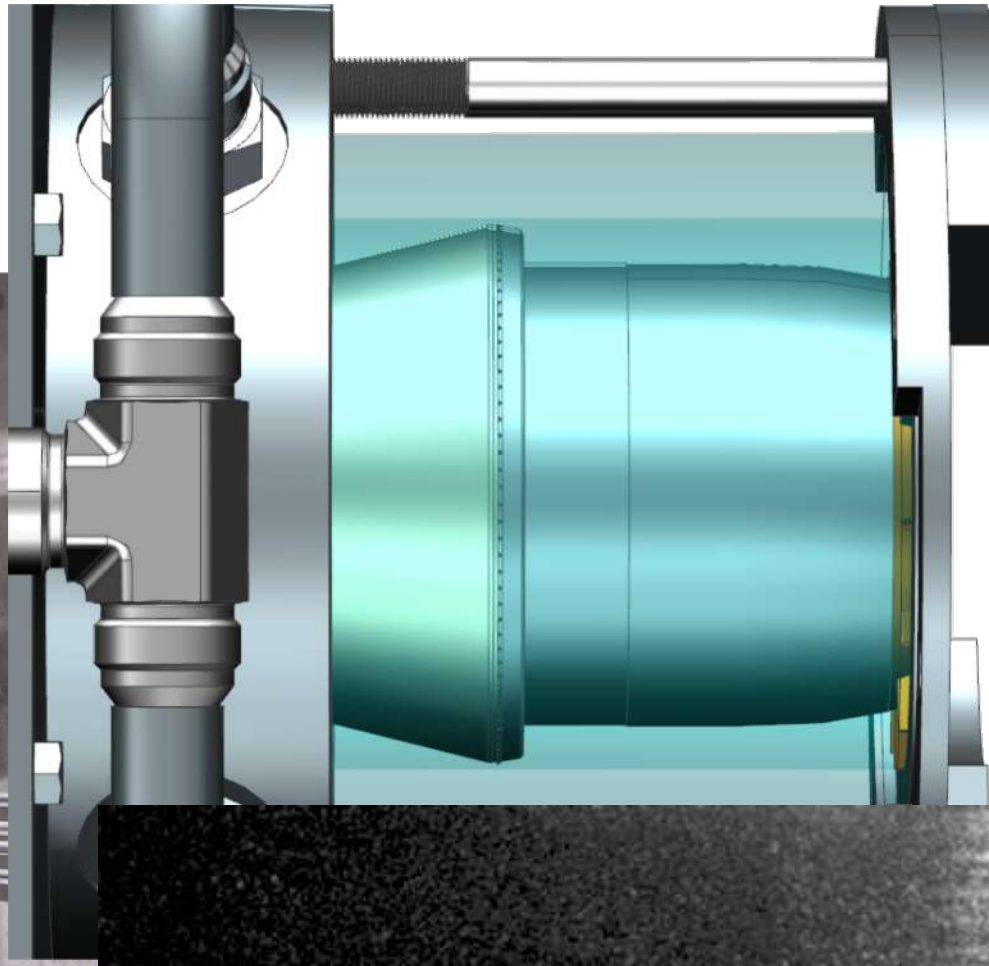


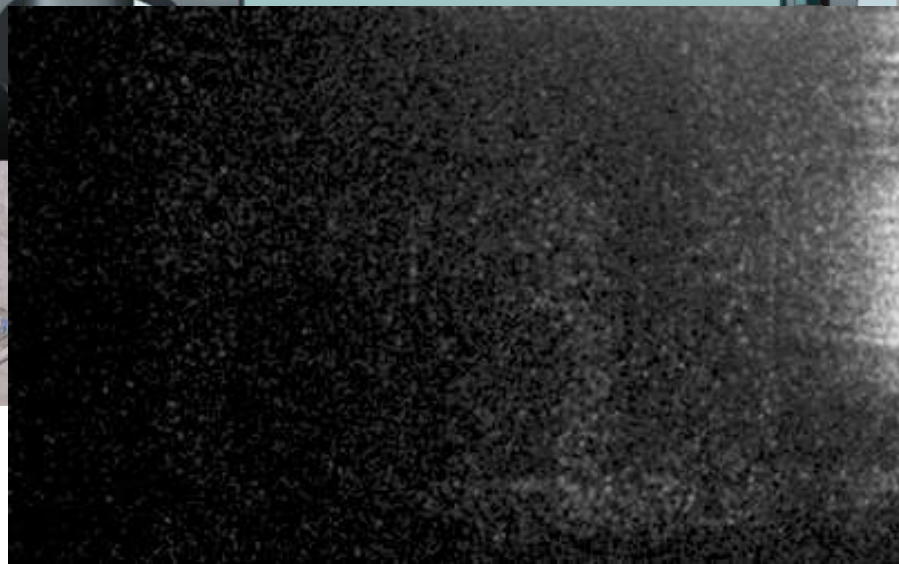


Experimental verification

Turbine-integrated High-pressure Optically-accessible RDE (THOR)







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