KTH ROYAL INSTITUTE
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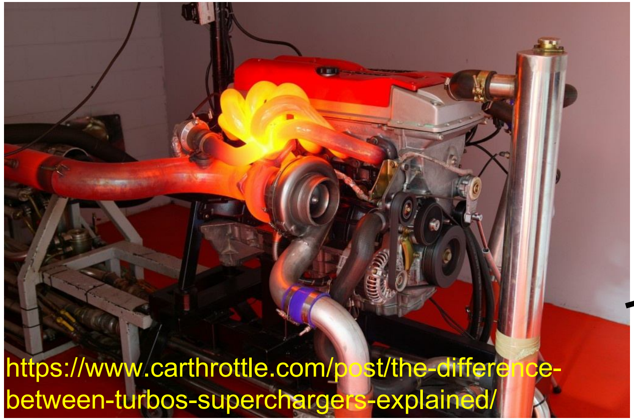
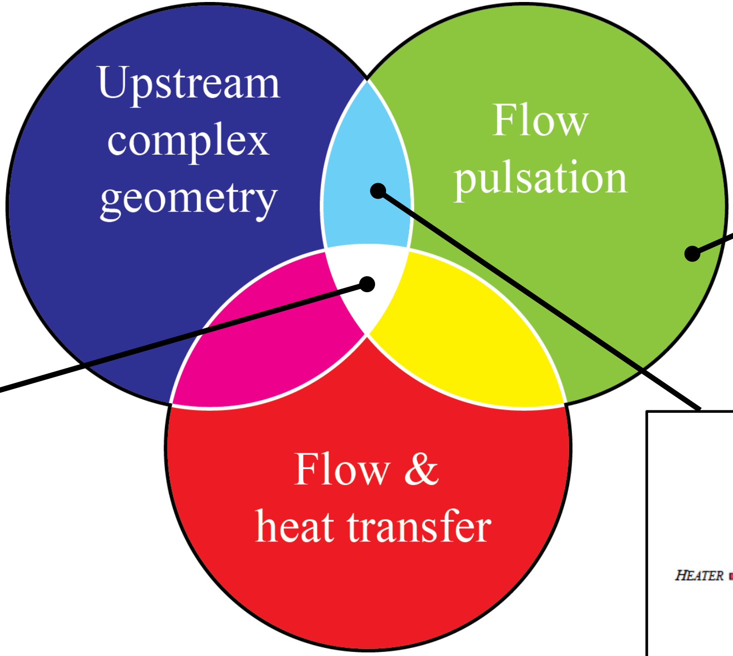
Aerothermodynamics and exergy analysis in turbocharger radial turbine

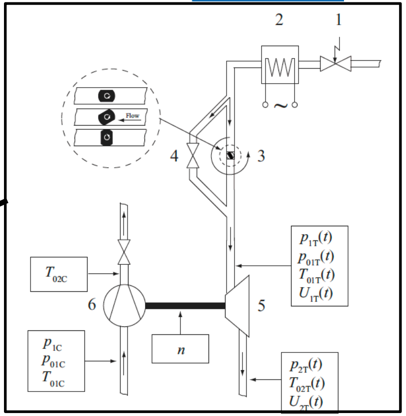
Shyang Maw Lim, Anders Dahlkild, Mihai Mihaescu

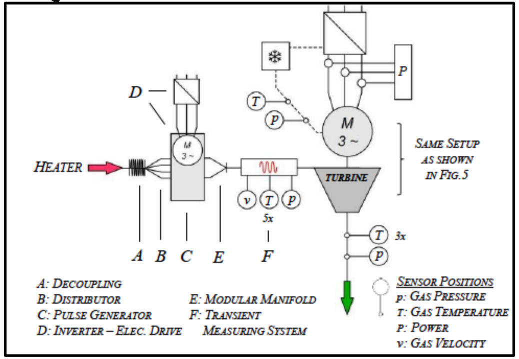
KTH Mechanics, Competence Center for Gas Exchange (CCGEx)

The turbocharger turbine





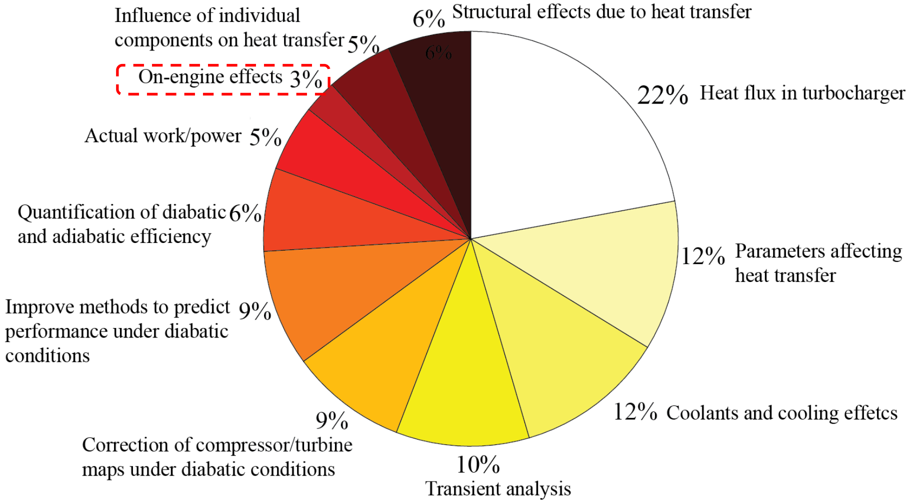




Laurantzon F, Örlü R, Segalini A, Tillmark N, Alfredsson H. Experimental analysis of turbocharger interaction with a pulsatile flow through time-resolved flow measurements upstream and downstream of the turbine. In: Institution of Mechanical Engineers - 10th International Conference on Turbochargers and Turbocharging [Internet]. 2012. p. 405–15.

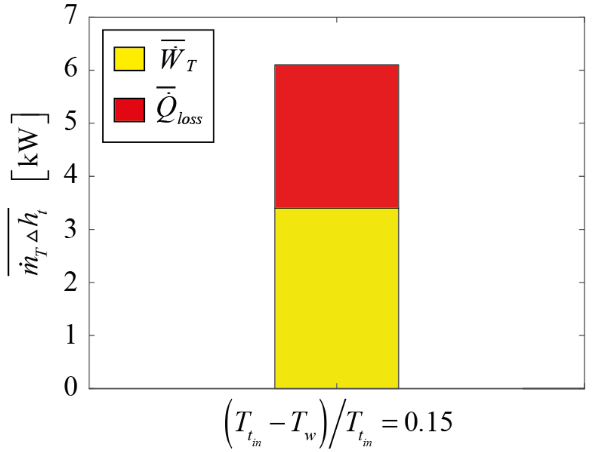
Lyttek P, Roclawski H, Böhle M, Gugau M. New Modular Test Rig for Unsteady Performance Assessment of Automotive Turbocharger Turbines. ASME. Turbo Expo: Power for Land, Sea, and Air, *Volume 8: Microturbines, Turbochargers and Small Turbomachines; Steam Turbines* ():V008T26A017. doi:10.1115/GT2017-64218.

Trend in heat transfer research



1st law of thermodynamics

$$\Delta h = q - w$$



Aerothermodynamic losses?

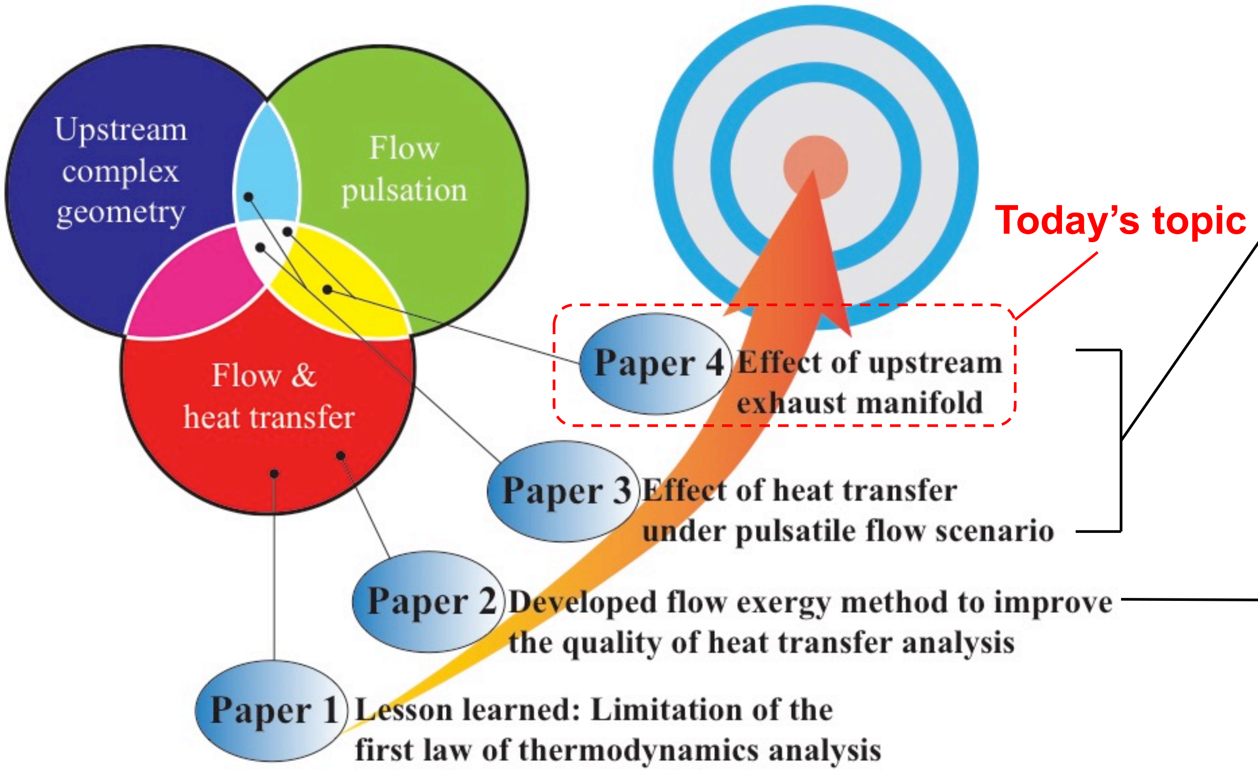
Romagnoli, A. Manivannan, S. Rajoo, M.S. Chiong, A. Feneley, A. Pesiridis, R.F. Martinez-Botas, "A review of heat transfer in turbochargers," *Renew. Sustain. Energy Rev.*, vol. 79, no. Supplement C, pp. 1442–1460, 2017

Research gaps & goal

- Limited insights into the thermo-fluid effects due to heat transfer with the first law of thermodynamic based method
- Customary set-up ignore the presence of the upstream exhaust manifold
- Limited knowledge about the thermo-fluid physics under on-engine conditions

Goal: *Understand the thermo-fluid physics and the turbine performance under realistic engine conditions*

Research questions & strategy



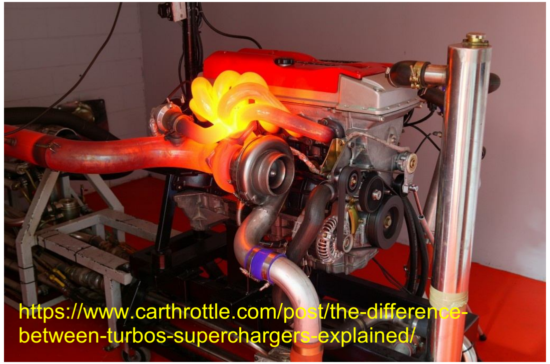
R3. What are the effects of upstream exhaust manifold on the heat transfer and performance of the turbine?

R1: What are the associated aerothermodynamic losses due to heat transfer?

R2: How can we quantify the losses?

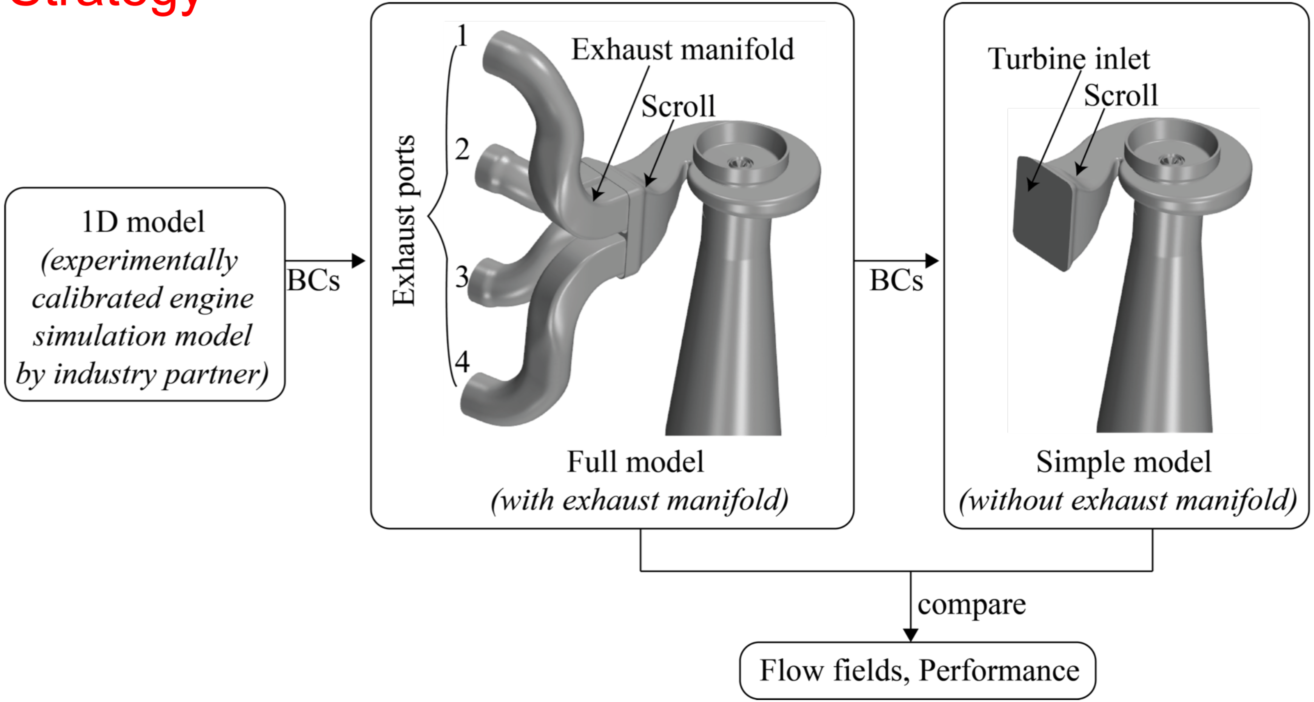
Challenges & strategy

Challenges

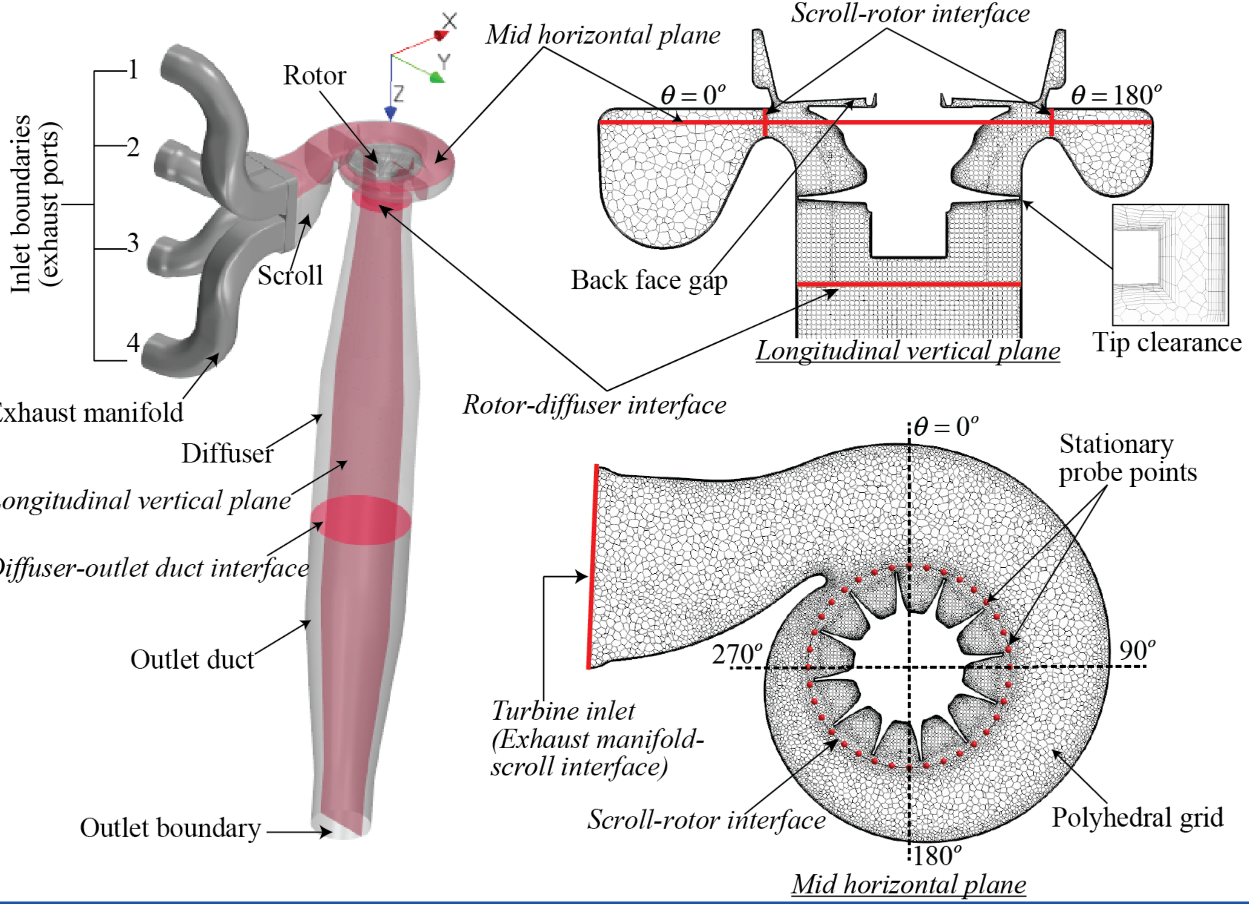


experiment measurement/ visualization

Strategy



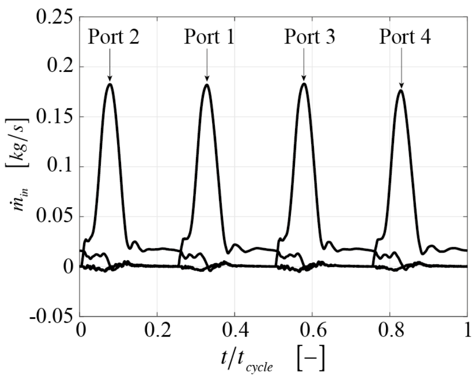
Computational model



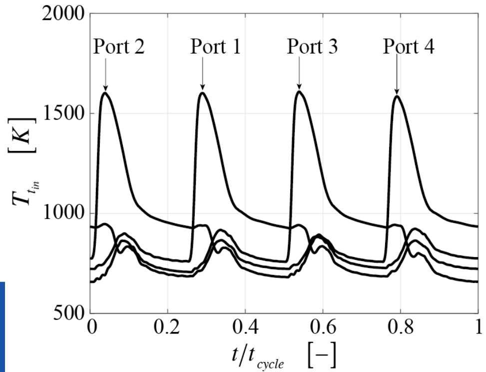
BCs: Full model

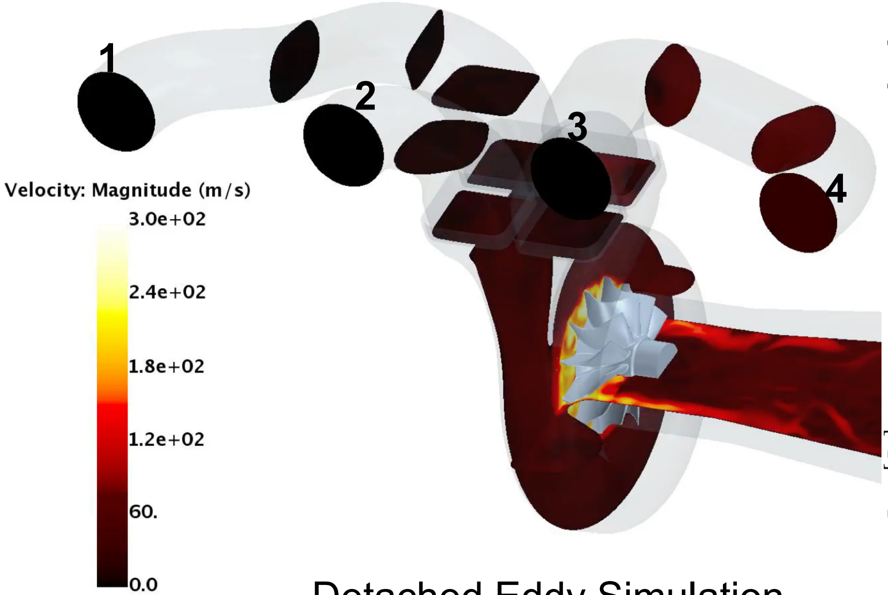
n_{engine}=1500 rpm

Inlet mass flow rate

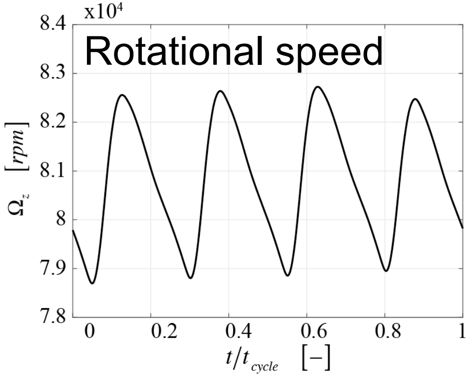


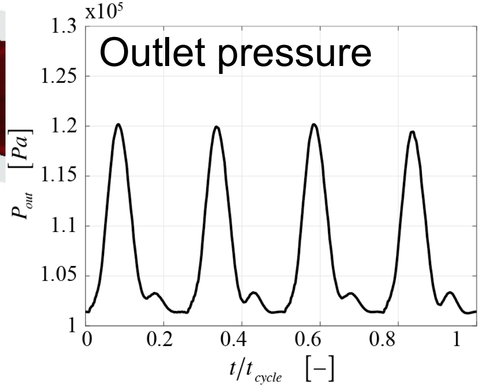
Inlet total temperature





Detached Eddy Simulation (DES)



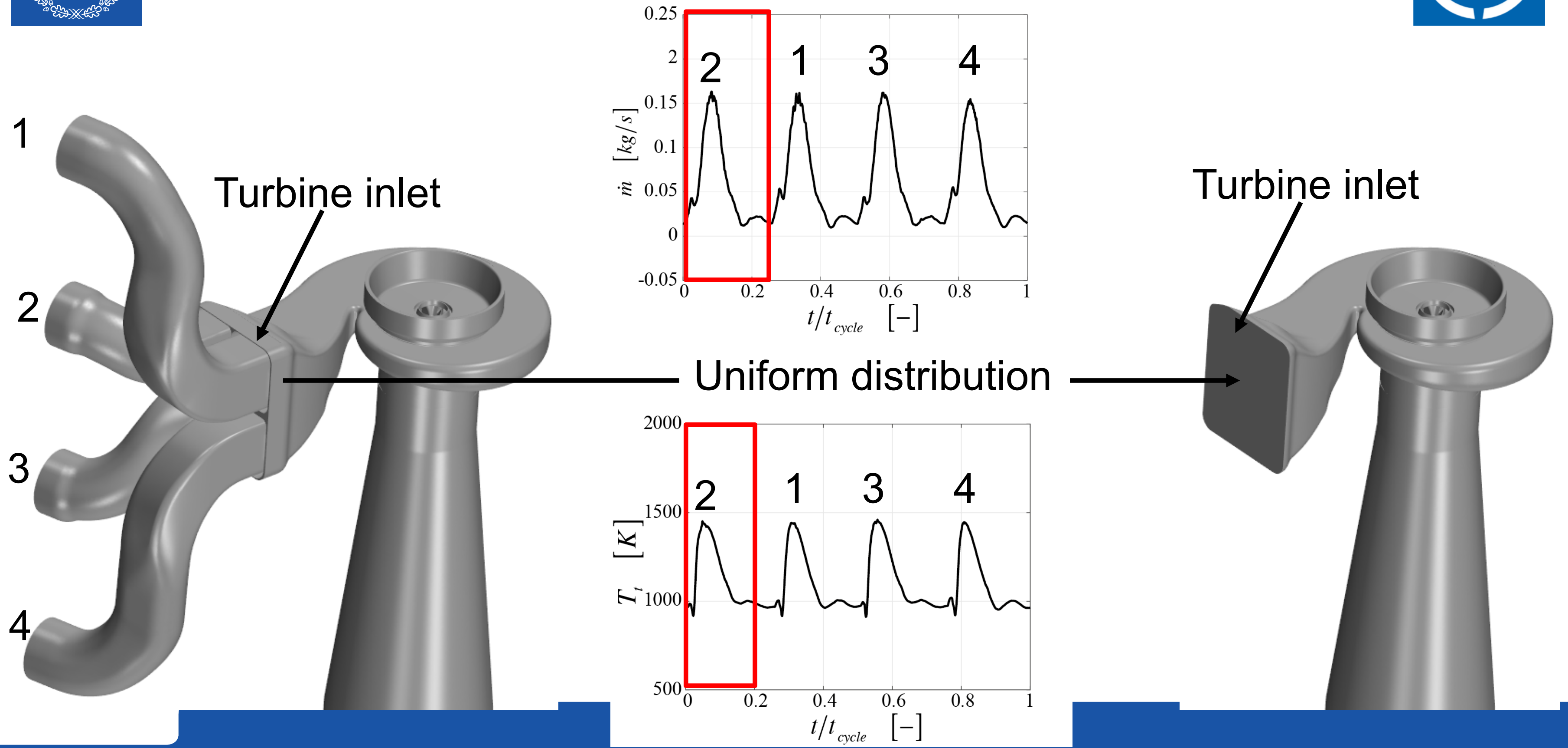


Thermal BCs

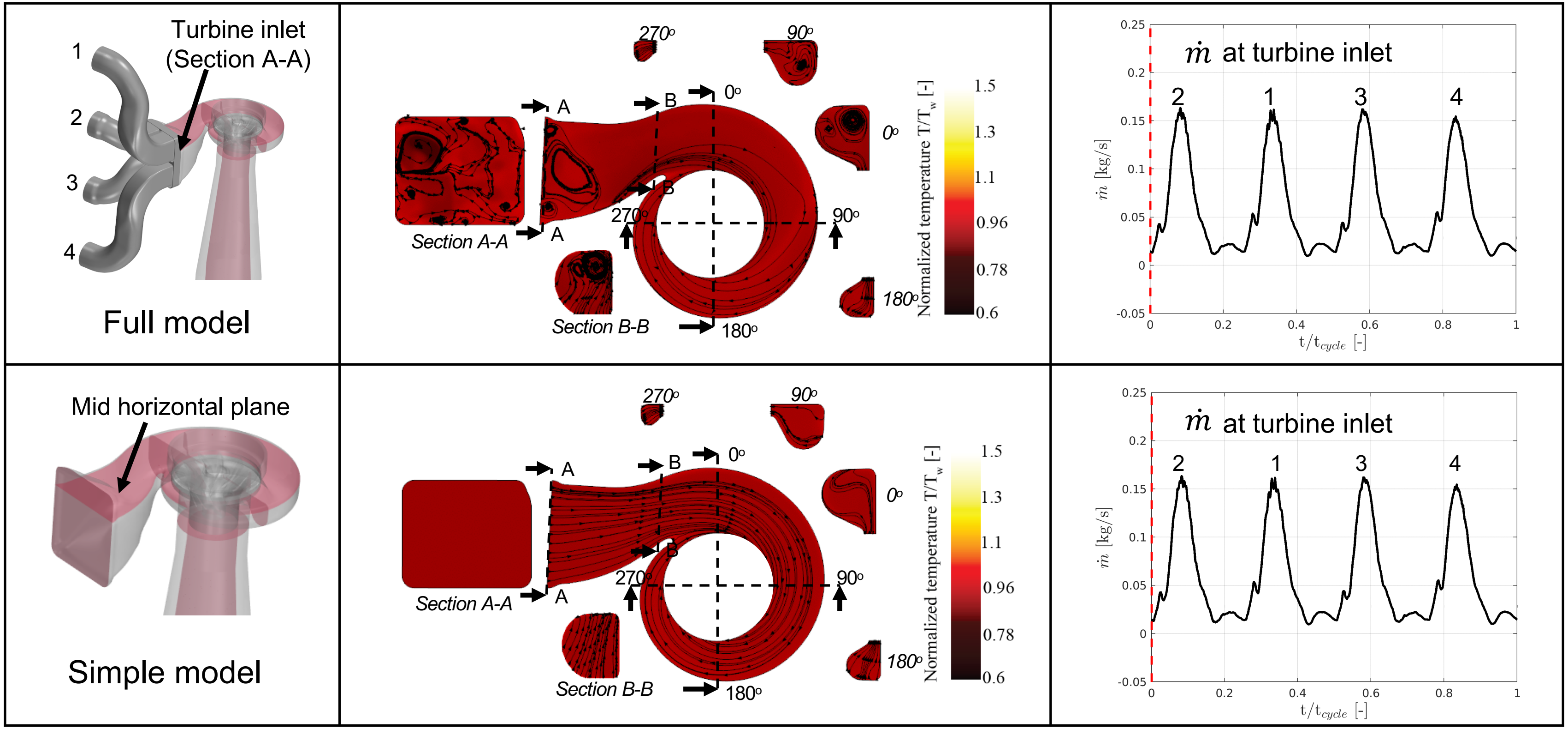
Component	Wall thermal conditions
Exhaust manifold & scroll	T_w= 1173 K
Rotor	Adiabatic
Diffuser & outlet duct	T_w= 929 K

**T_w* *is the estimated average solid-fluid wall temperature from 1D model*

BCs: Simple model

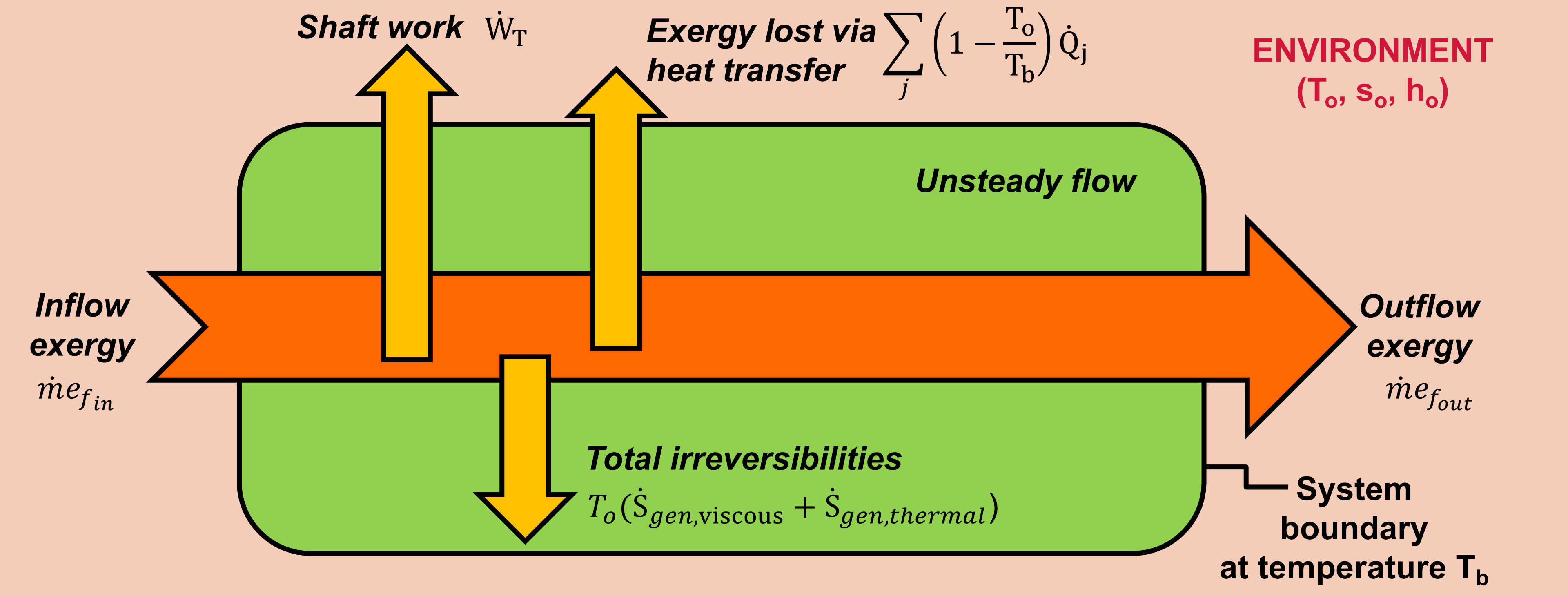


Flow field (1500 rpm)



Flow exergy

$$e_f = [h_t(T_t) - h_o] - T_o[s(T,p) - s_o]$$



$$\dot{S}_{gen,viscous} = \iiint_{V^*(t)} \left[\frac{\mu_{mol} + \mu_{turb}}{T} \Phi\right] dV \qquad \dot{S}_{gen,thermal} = \iiint_{V^*(t)} \left[\frac{k_{mol} + k_{turb}}{T^2} (\nabla T)^2\right] dV$$

Flow exergy budget

$$-\oiint_{S^*(t)} \rho e_f (\vec{u} - \vec{u}_b) \cdot \vec{n}\, dS$$

Flow exergy change (Inflow - Outflow)

$$= \frac{d}{dt}\left[\iiint_{V*(t)} (\rho e_f)\, dV\right] - \frac{d}{dt}\left[\iiint_{V*(t)} p\, dV\right]$$

= Unsteadiness

Physical interpretation

$$+ \oiint_{S^*(t)} [(\vec{r} \times \vec{f}_{net}) \cdot \vec{\Omega}] dS$$

+ Exergy transferred by shaft work

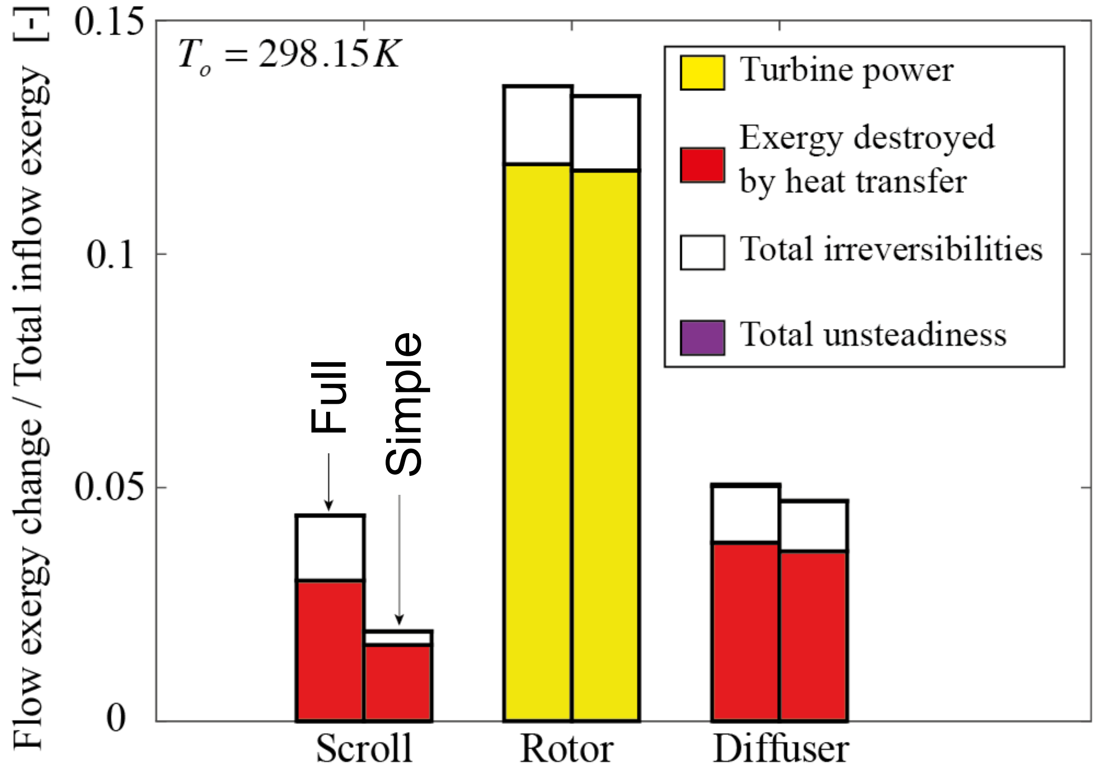
$$+ \oiint_{S^*(t)} \left[\left(1 - \frac{T_o}{T_b}\right)\right] (\vec{q} \cdot \vec{n}) dS$$

+ Exergy gained/lost by heat transfer

$$+ T_o\left(\dot{S}_{gen,viscous} + \dot{S}_{gen,thermal}\right)$$

+ Exergy destroyed by irreversibilities

Flow exergy budget (1500 rpm)

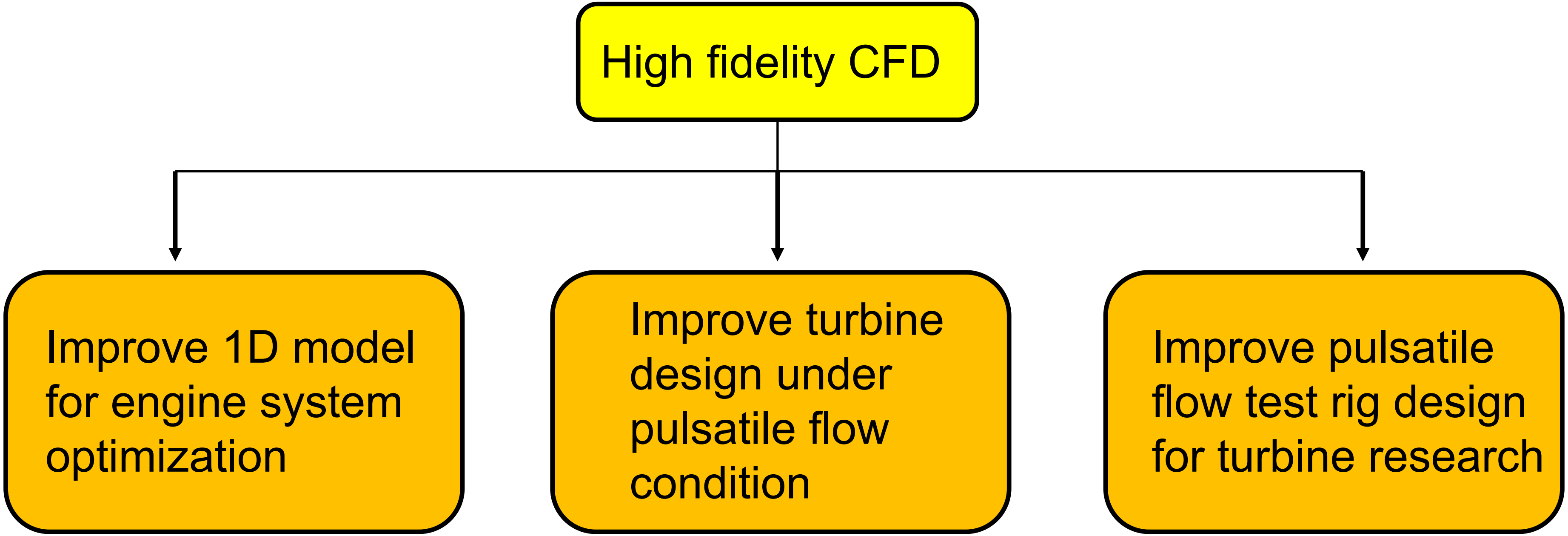


- Scroll is most affected
- Turbine power is relatively unaffected

Conclusions

- What are the effects of upstream exhaust manifold on the heat transfer rate and performance of the turbine?
  - Fundamental thermo-fluid physics (i.e. secondary flow) in the scroll is governed by exhaust manifold
  - Heat transfer rate & aerothermodynamic losses increase
  - Turbine power is relatively unaffected

Future challenges



Competence Center for Gas Exchange

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