

Prof. Dr.-Ing. Dieter Brillert

Chair of Turbomachinery

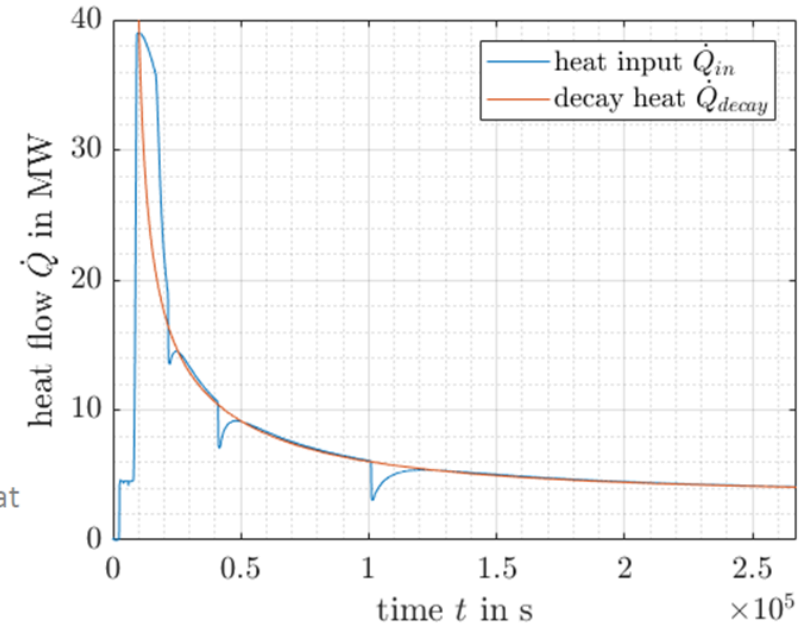
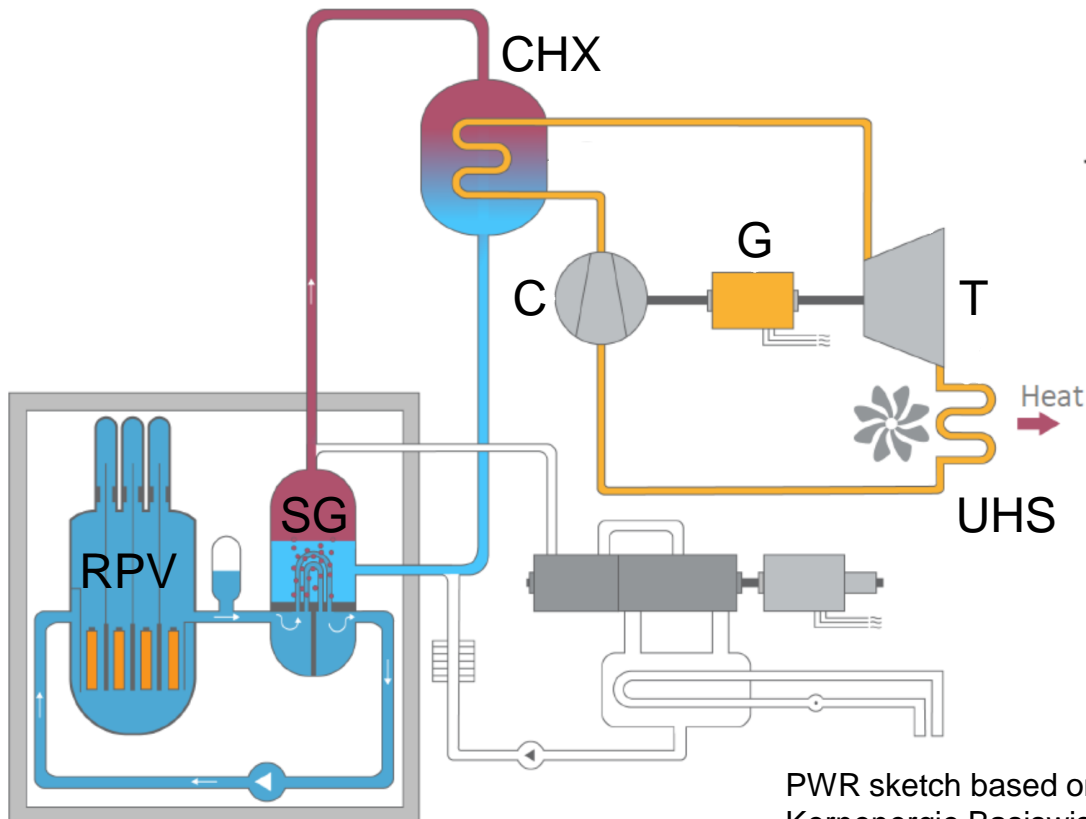
Mean-line Analysis for Supercritical CO₂ Centrifugal Compressors by using Enthalpy Loss Coefficients

Haikun Ren, M.Sc. ■ 24-03-2021



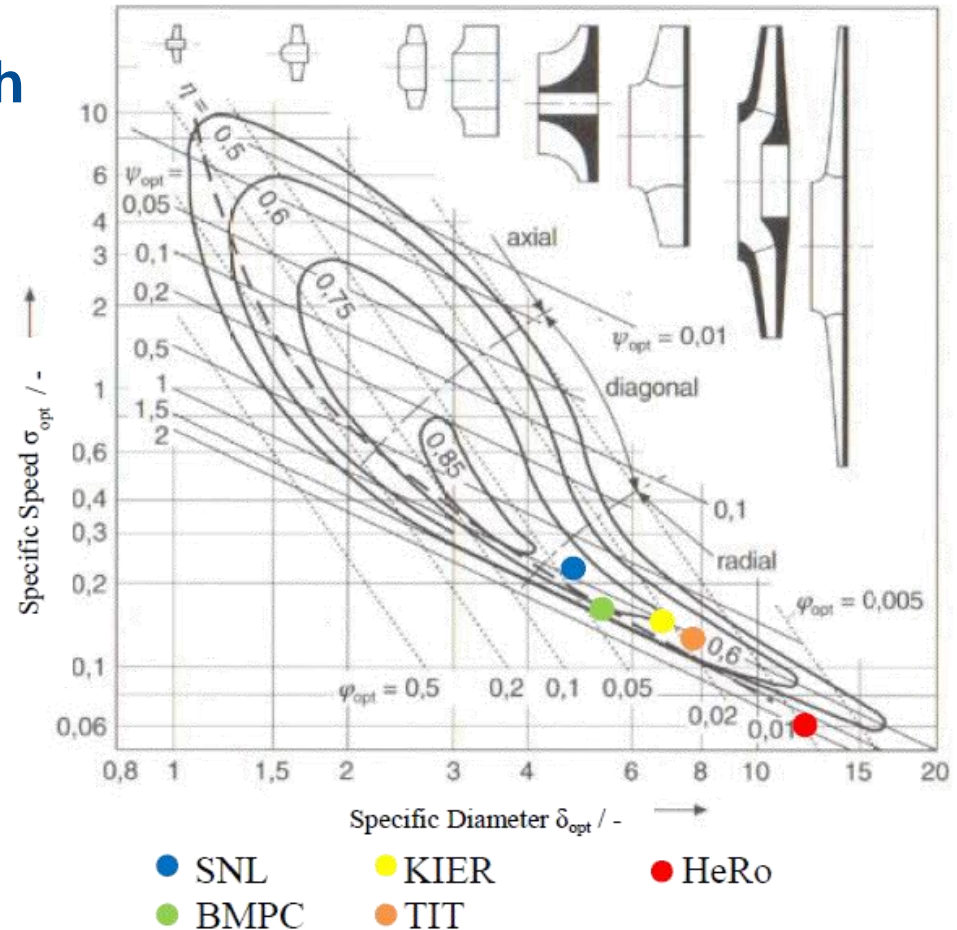
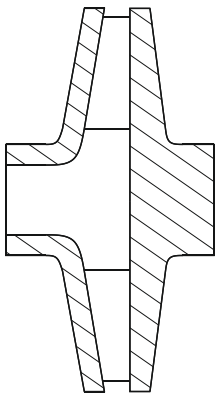
sCO₂-4-NPP

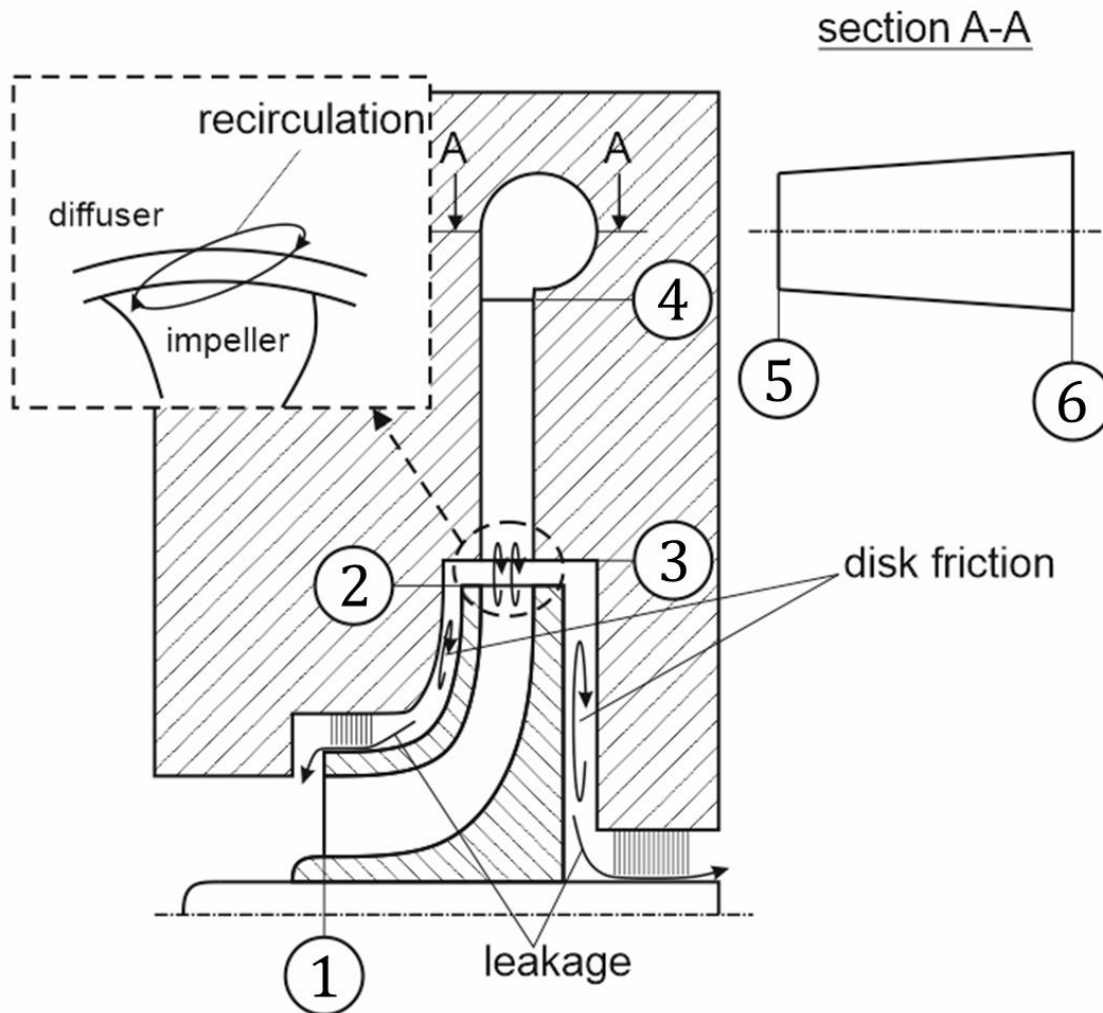
- New cycle design for back-up cooling in NPPs
- New turbomachinery in sCO₂-4-NPP project
- Quick and reliable for predicting performance of sCO₂ centrifugal compressors



PWR sketch based on Martin Volkmer DAfF Deutsches Atomforum e.V.
Kernenergie Basiswissen page 50

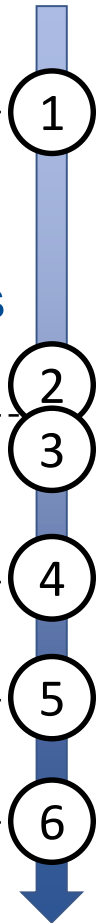
- Mean-line analysis with enthalpy loss coefficients
- Quantitative verification with the compressor in sCO₂-HeRo project:
 - 2D shrouded impeller
 - Very low specific speed





Internal losses

- 1 incidence loss
- 2 skin friction loss
- 3 blade loading loss
- 4 wake mixing loss
- 5 vaneless diffuser loss
- 6 volute loss
- exit cone loss



Inputs:

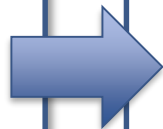
- Inlet conditions:
 $p_{t1}, T_{t1}, N, \dot{m}$
- Geometry:
 $d_1, d_2, \beta_1, \beta_2, \dots$
- Configuration:
 - Parasitic works?
 - ...

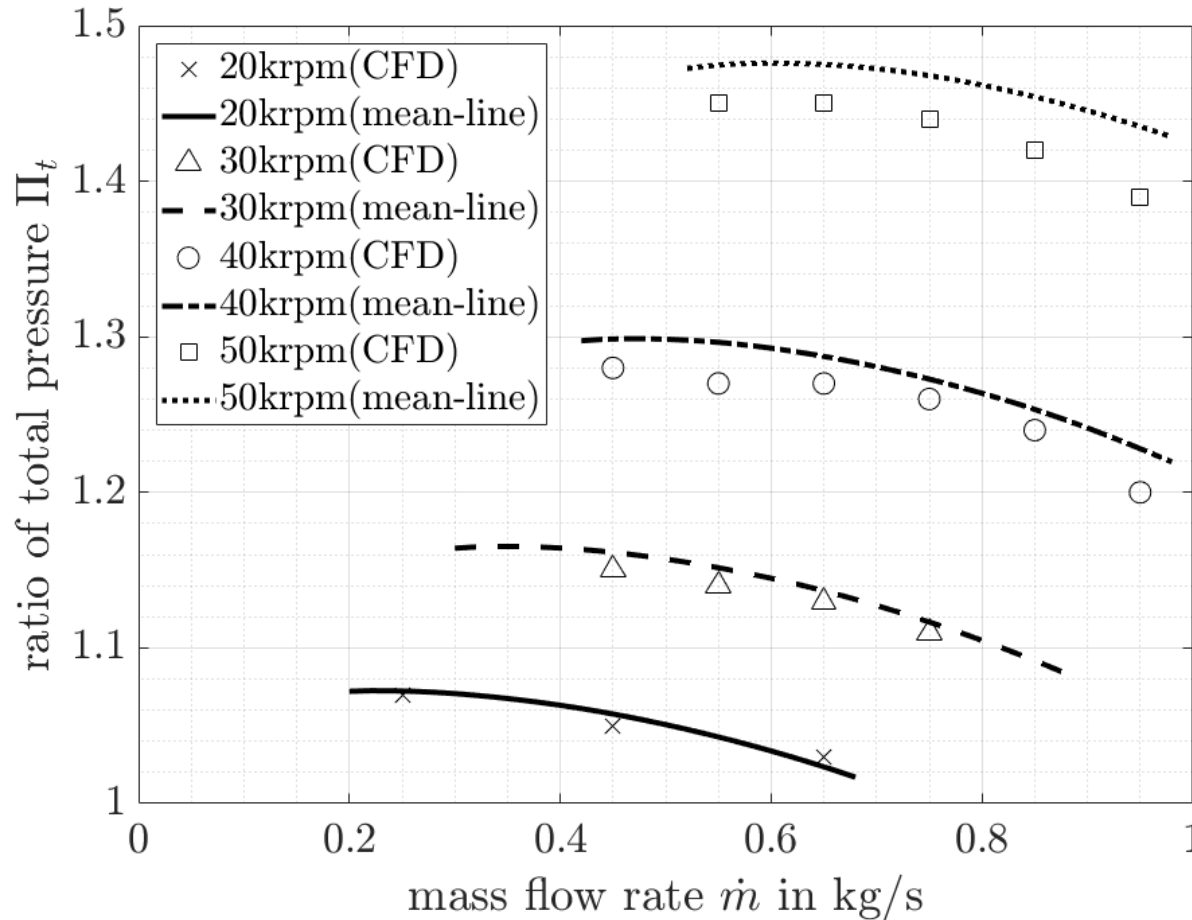
Models:

- Mean-line analysis
- Enthalpy loss coefficients:
 $\zeta_{inc}, \zeta_{sf}, \zeta_{bld}, \zeta_{mix}, \zeta_{vld}, \dots$
- Other models:
 - Leakage model
 - Pressure drop in rotating cavity
 - ...

Outputs:

- Outlet conditions:
 $p_{t6}, T_{t6}, h_{t6}, h_{t6,is}, \dots$
- Performance:
 $\Pi_t, \eta_t, \Delta h_{t,is}, \dots$
- Performance maps:
 - Π_t vs \dot{m}
 - $\Delta h_{t,is}$ vs \dot{m}
 - η_t vs \dot{m}
 - ...





[Data from project sCO₂-HeRo]

Π_t vs \dot{m}

$$\Pi_t = \frac{p_{t6}}{p_{t1}}$$

$$\Delta_{\Pi} = \frac{|\Pi_{t,CFD} - \Pi_{t,ML}|}{\Pi_{t,ML}} \times 100\%$$

$$\Delta_{\Pi,max} = 3.2\%$$

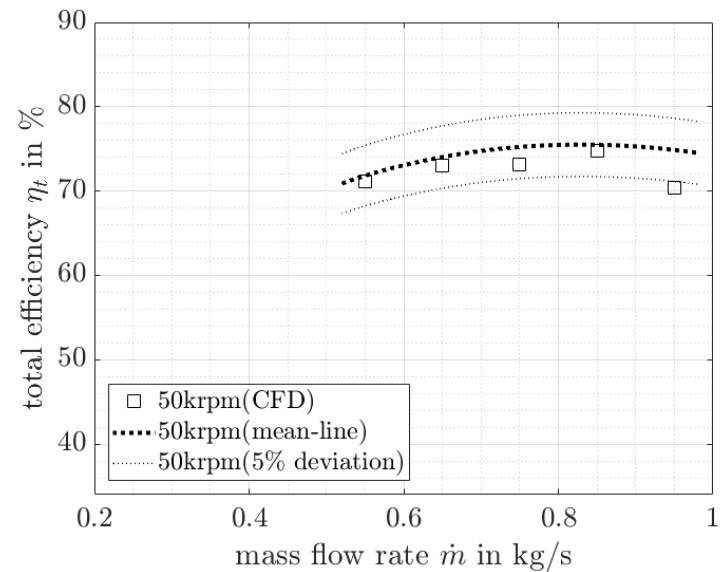
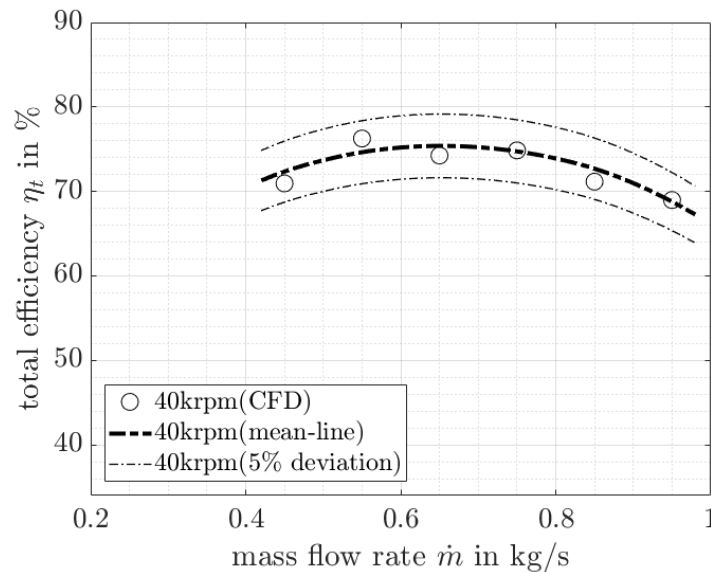
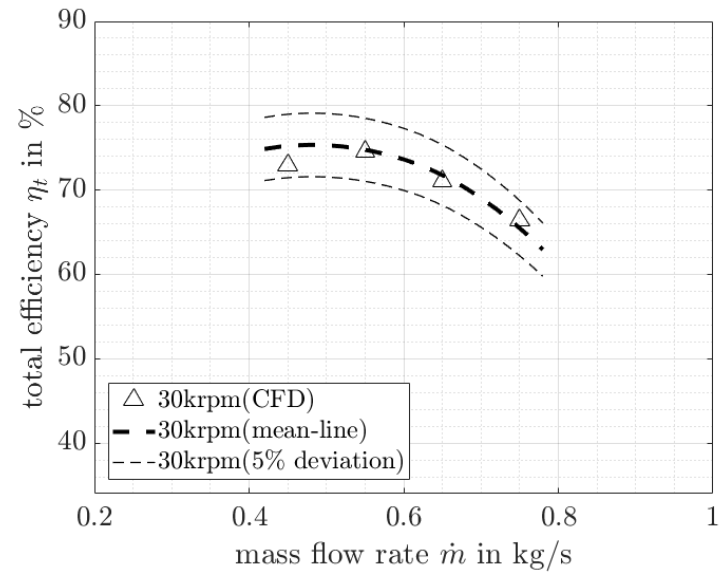
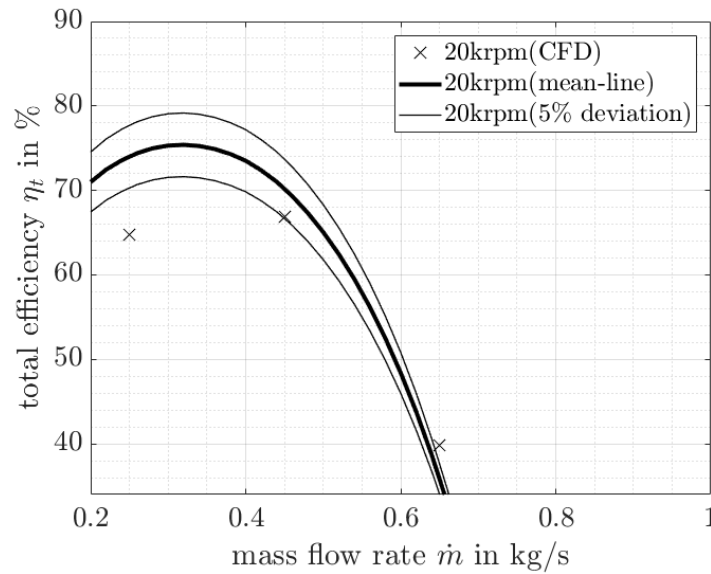
$\Delta h_{t,is}$ vs \dot{m}

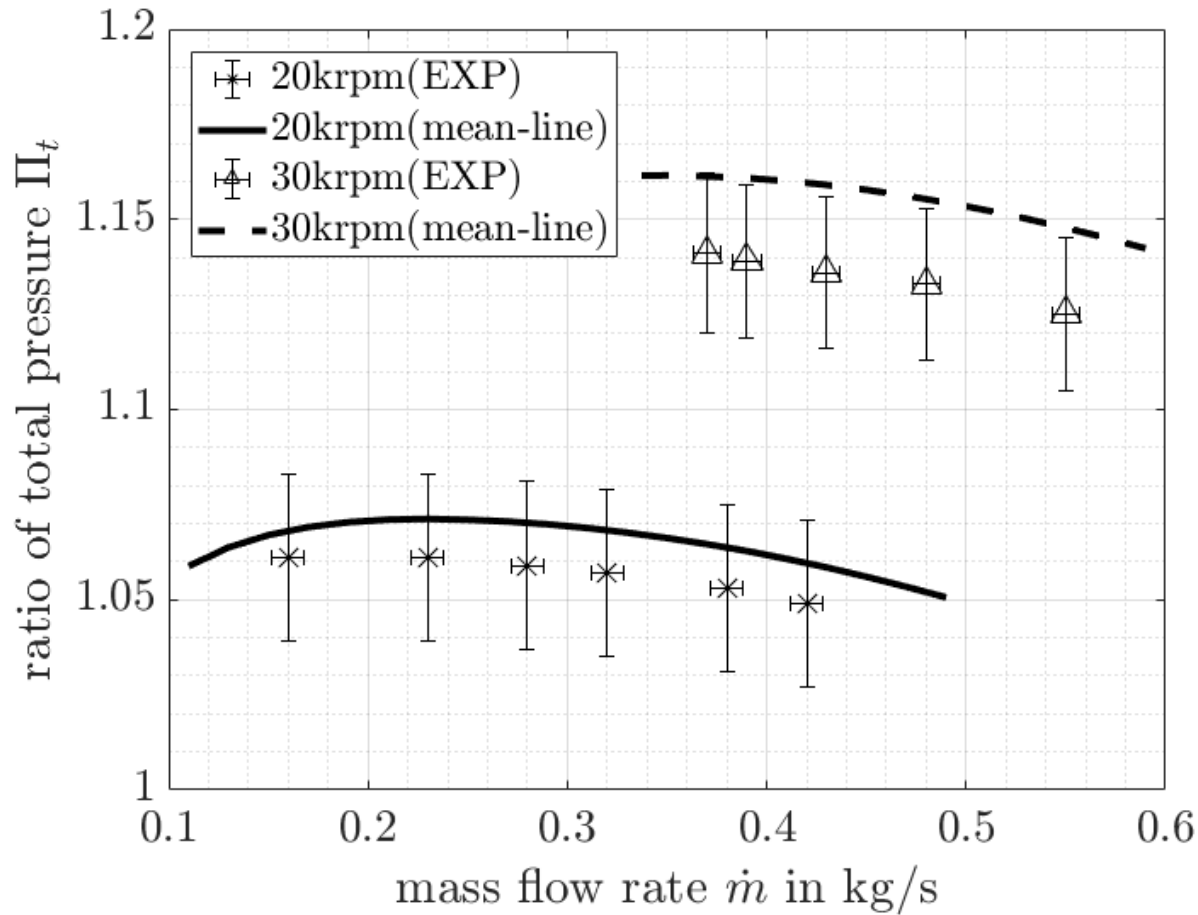
$\Delta h_{t,is}$ is similar to Π_t

77.8% of the cases within 5% deviation



Results: Mean-line vs CFD





Π_t vs \dot{m}

$$\Delta_{\Pi} = \frac{|\Pi_{t,EXP} - \Pi_{t,ML}|}{\Pi_{t,ML}} \times 100\%$$

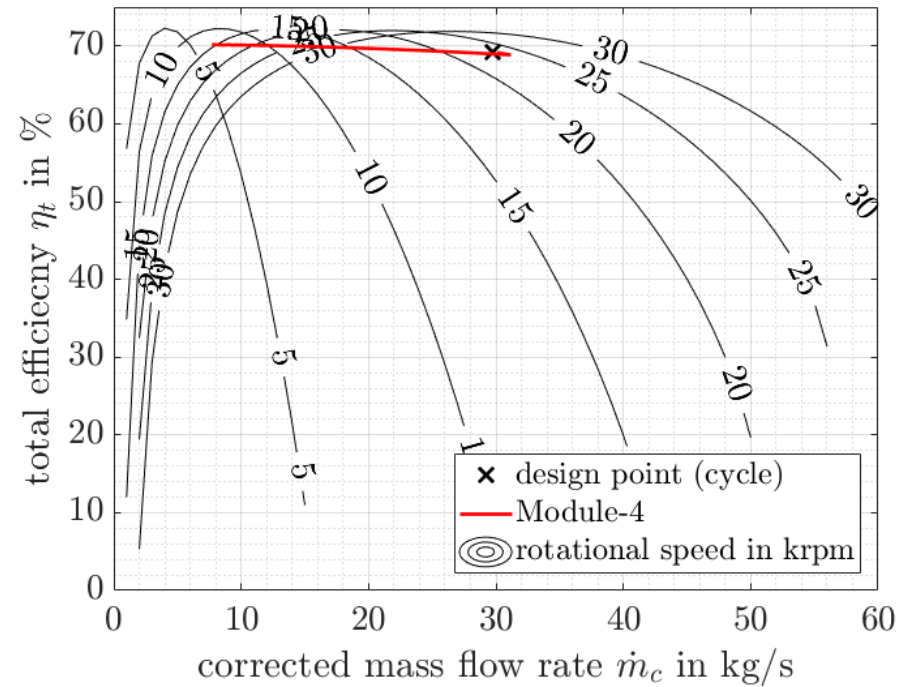
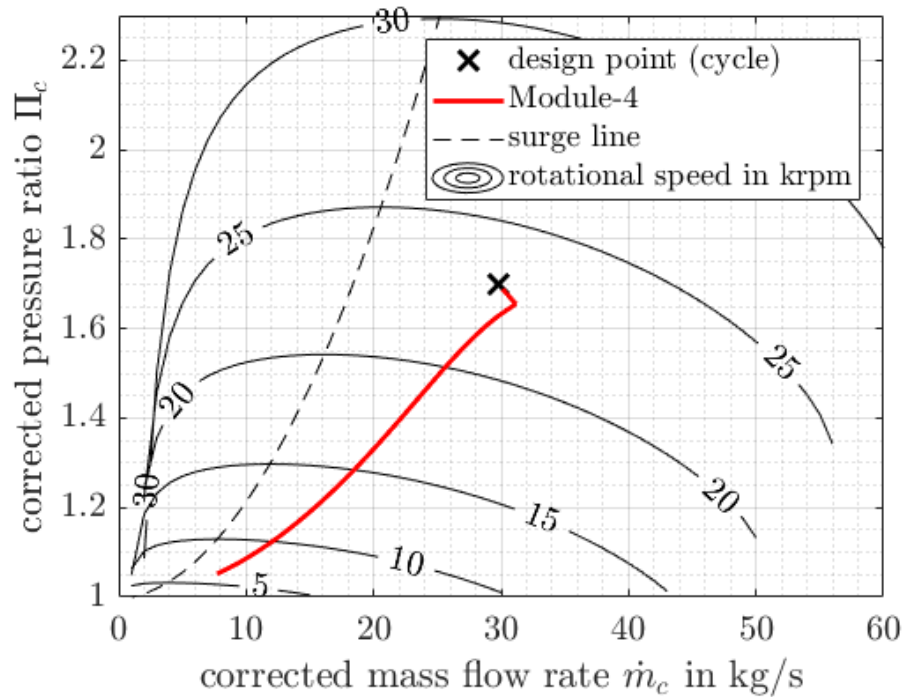
$$\Delta_{\Pi,max} = 3.9\%$$

Parasitic works considered

[Data from experiments in SUSEN loop at CVR]



Performance maps of new designed compressor in project sCO₂-4-NPP



- Inside operation range
- Safe operation to the surge line
- Operation at relatively high efficiency level



- **Enthalpy loss coefficient set is verified against sCO₂-HeRo compressor**
- **Off-design tool is validated within 5% deviation in efficiency**
- **Off-design tool is validated within 4% deviation in pressure ratio**
- **Quick and robust performance prediction for sCO₂ centrifugal compressors with same or similar configuration like sCO₂-4-NPP compressor**

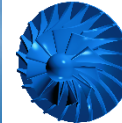


**Thank you for your
attention!**

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Prof. Dr.-Ing. Dieter Brillert

Chair of Turbomachinery



HORIZON 2020



sCO₂-4-NPP