# Towards real time transient mGT performance assessment:

## Effective prediction through efficient adaption of component maps

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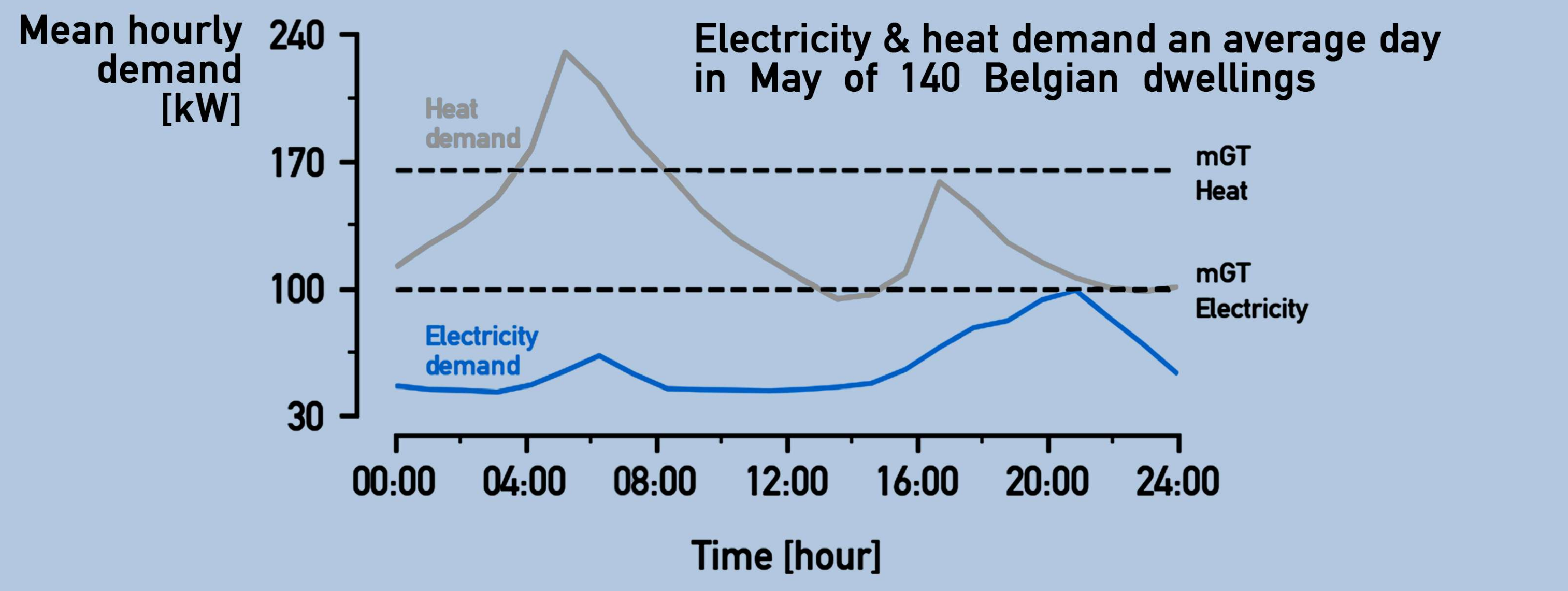
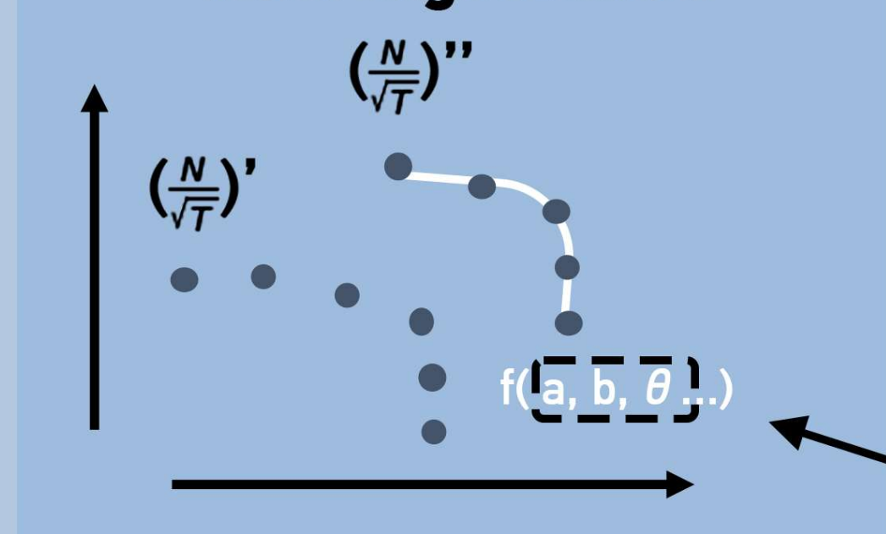
## mGTs need to operate with flexibility in the future energy mix

The increasing demand of heat & power in the industry coupled with the today's emission reduction targets has led Micro Gas Turbines (mGT) to perform transient operations as part of a flexible power grid. It is essential to enhance the fidelity of dynamic simulations by performing fast calculations and including experimental data.



## Map adaptation for Compressor & Turbine



**Obtain data from digitization**

**Find the parameters of the fitting curve for each corrected speed**

Fit the data to a curve *f*(a, b, *θ*...) with an algorithm that minimizes the RMS error [1]

**3 equations (cases) were tested for each map adaptation**

Perform polynomial interpolation of the coefficients for each case (i) with the corrected speed

$$a_i = \mathrm{f}\left(\frac{N}{\sqrt{T}}\right),\ b_i = \mathrm{f}\left(\frac{N}{\sqrt{T}}\right), \ldots.$$

## Compressor

Three cases are applied to determine the relation between **Reduced mass-flow** and **Pressure ratio.** Each regression parameter is estimated at the available corrected speeds and can be interpolated to any other. This is depicted in the figure for Case 1.

**Case 1:** Ellipse

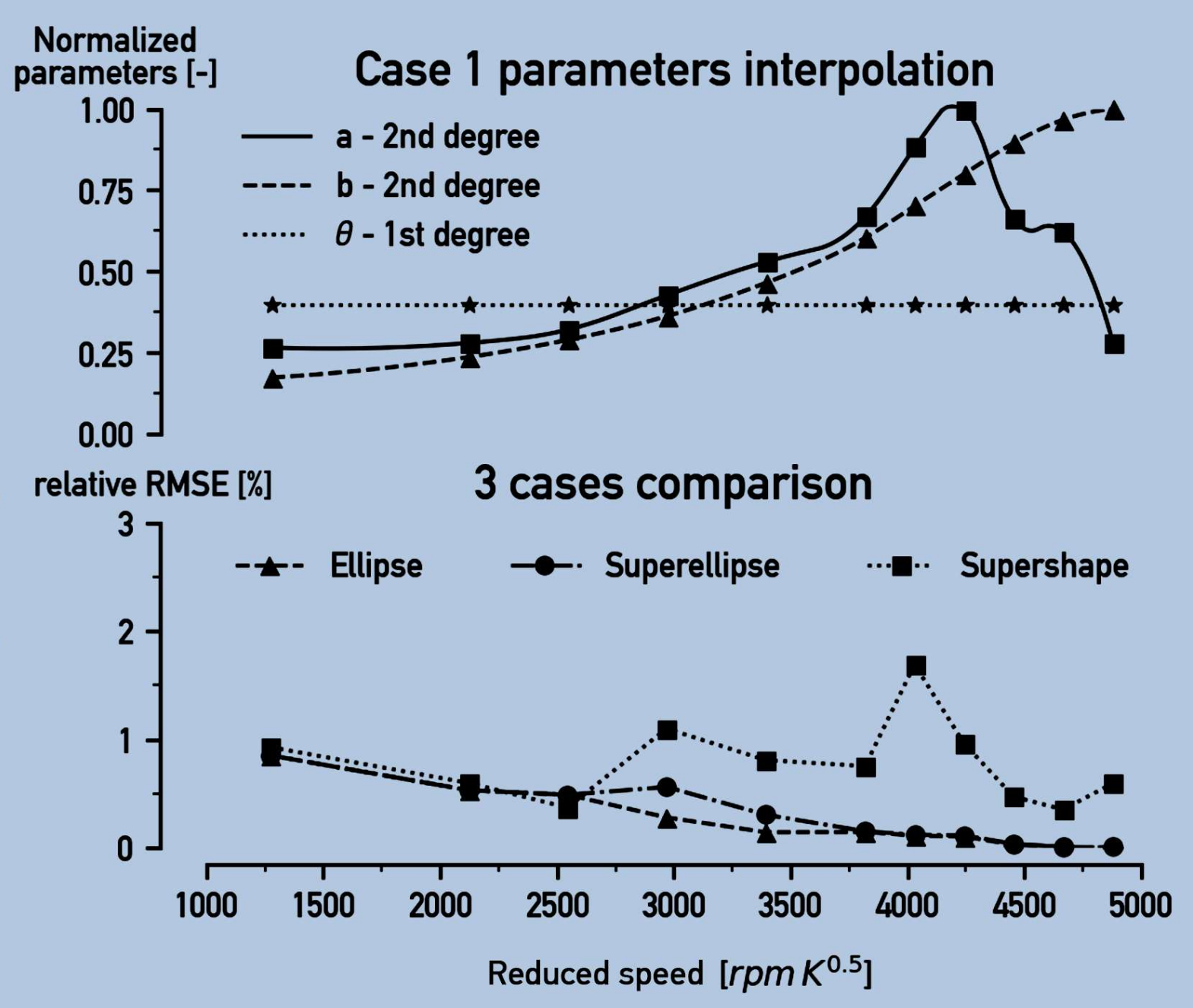
$$\left|\frac{m_{c0}}{a}\right|^2 + \left|\frac{\pi_{c0}}{b}\right|^2 = 1$$

**Case 2:** Superellipse

$$\left|\frac{m_{c0}}{a}\right|^n + \left|\frac{\pi_{c0}}{b}\right|^n = 1$$

**Case 3:** Supershape

$$\left|\frac{m_c - x_0}{a}\right|^{n_2} + \left|\frac{\pi_c}{b}\right|^{n_3} = 1$$

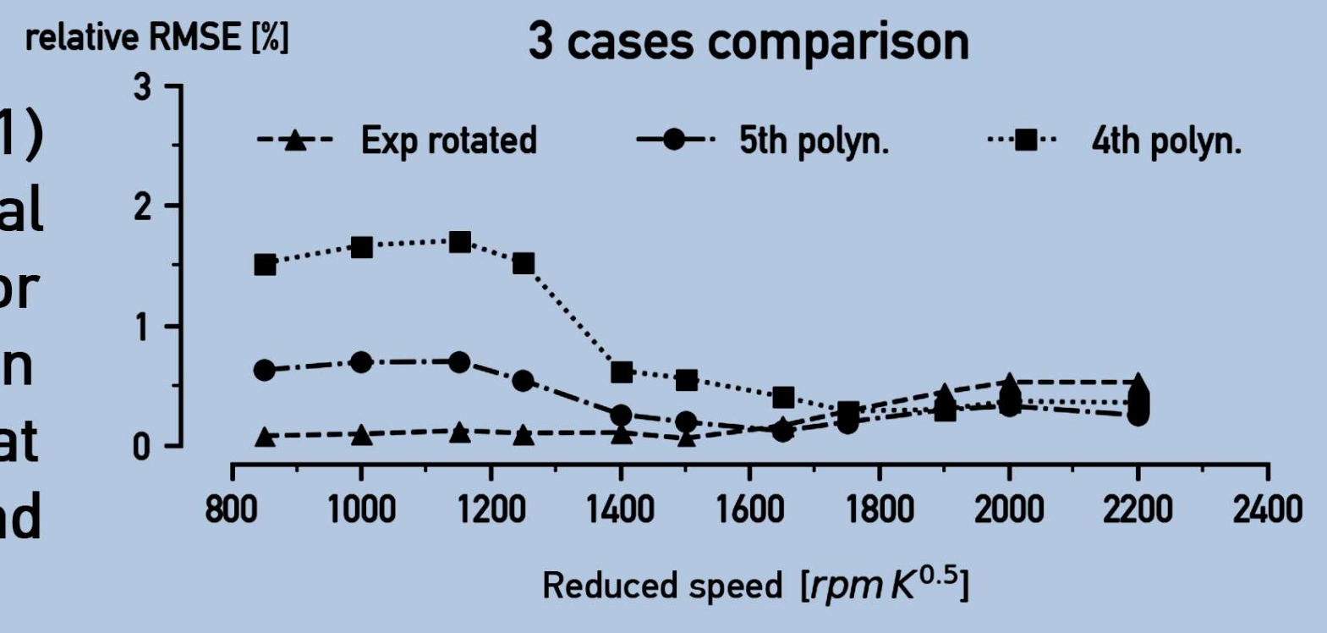


Case 1 is preffered as it minimizes the RMSE from the compressor map data. Simillar procedure is followed for the efficiency curves.

## Turbine

Here an exponential rotated function (Case 1) is compared to 4th and 5th degree polynomial fitting functions. Case 1shows minimum error in the low shaft speeds and 5th polynomial in high speeds. A hybrid function is adopted that uses Case 1 at speeds below 1750rpmK$^{0.5}$ and Case 2 for the rest.

The same method is pursued for the turbine efficiency and is presented as a function of expansion ratio and shaft speed.



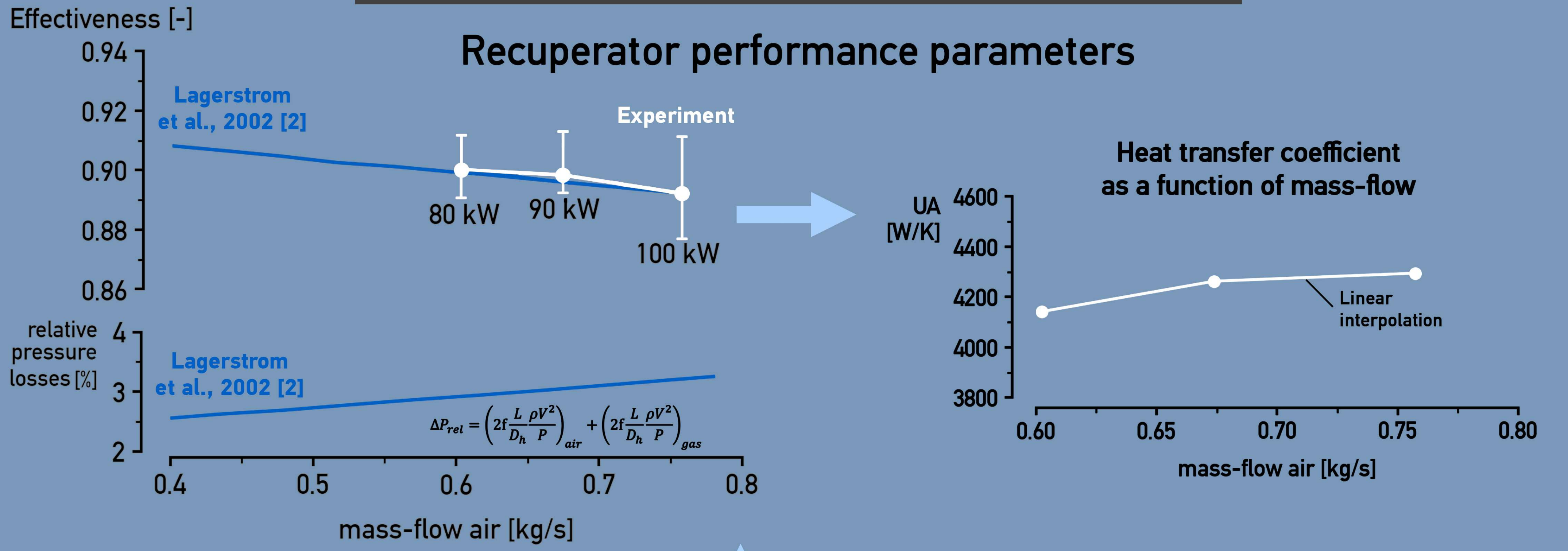
**Case 1:** Exponential rotated $\dot{m}_{t0} = b^{(\pi_{t0}+a)} + c$

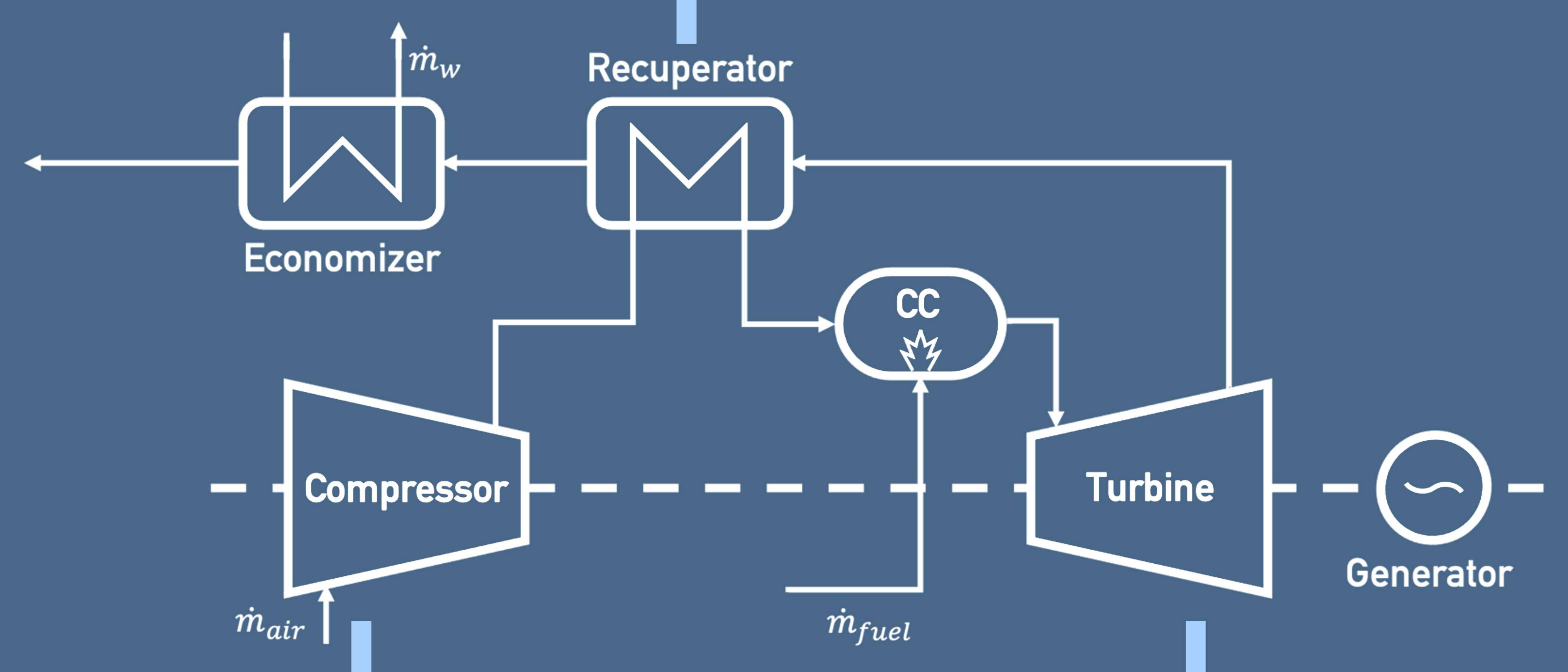
**Case 2:** 5th degree polynomial

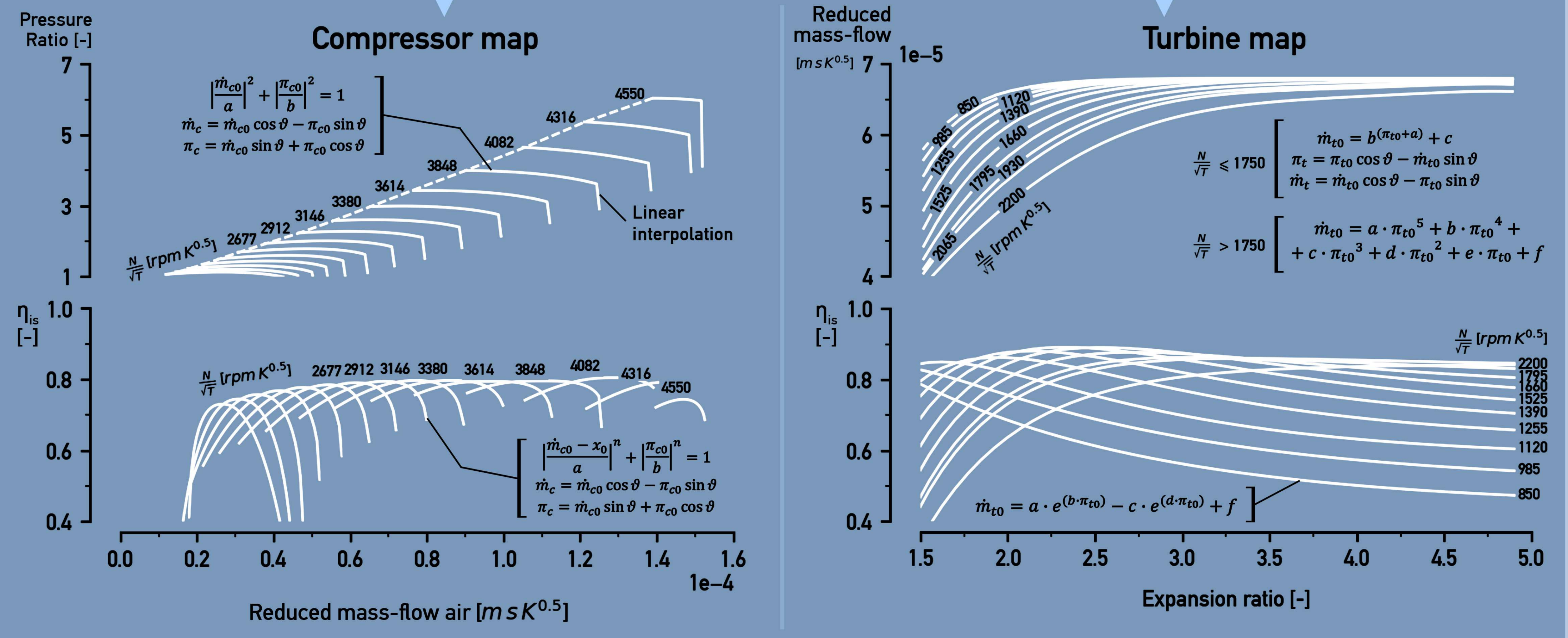
**Case 3:** 4th degree polynomial

### Objective

Enhance the acurracy of dynamic mGT cycle modeling by computational efficient incorporation of experimental data







Compressor map, pressure ratio:

$$\left|\frac{\dot{m}_{c0}}{a}\right|^2 + \left|\frac{\pi_{c0}}{b}\right|^2 = 1,\quad \dot{m}_c = \dot{m}_{c0}\cos\vartheta - \pi_{c0}\sin\vartheta,\quad \pi_c = \dot{m}_{c0}\sin\vartheta + \pi_{c0}\cos\vartheta$$

Compressor map, efficiency:

$$\left|\frac{\dot{m}_{c0} - x_0}{a}\right|^n + \left|\frac{\pi_{c0}}{b}\right|^n = 1,\quad \dot{m}_c = \dot{m}_{c0}\cos\vartheta - \pi_{c0}\sin\vartheta,\quad \pi_c = \dot{m}_{c0}\sin\vartheta + \pi_{c0}\cos\vartheta$$

Turbine map, reduced mass-flow:

$$\frac{N}{\sqrt{T}} \leqslant 1750 \quad \left[\ \dot{m}_{t0} = b^{(\pi_{t0}+a)} + c,\quad \pi_t = \pi_{t0}\cos\vartheta - \dot{m}_{t0}\sin\vartheta,\quad \dot{m}_t = \dot{m}_{t0}\cos\vartheta - \pi_{t0}\sin\vartheta \right.$$

$$\frac{N}{\sqrt{T}} > 1750 \quad \left[\ \dot{m}_{t0} = a\cdot\pi_{t0}^{\ 5} + b\cdot\pi_{t0}^{\ 4} + c\cdot\pi_{t0}^{\ 3} + d\cdot\pi_{t0}^{\ 2} + e\cdot\pi_{t0} + f \right.$$

Turbine map, efficiency:

$$\dot{m}_{t0} = a\cdot e^{(b\cdot\pi_{t0})} - c\cdot e^{(d\cdot\pi_{t0})} + f$$

Produced perfomance maps of Turbec T100 engine

### Conclusions

The data provided by the manufacturer or extracted by experiments are effectively adopted in the dynamic model of the mGT. The map adaptation provides a fast technique to include perfomance maps not only for the T100 but also for other mGT engines. The experimental data of the recuperator proved beneficial as it increased the fidelity of dynamic prediction of the component.

## Experimental data is used for recuperator performance determination

Heat transfer coefficient (UA) depends on the flow velocity and the temperature difference across the transfer area. After the implementation of experimental data from three operating points, the effectiveness is calculated and the UA is presented as a function of the working fluid mass-flow.

**Calculate recuperator effectiveness [ε] values**

$$\varepsilon = \frac{T_{air,out} - T_{air,in}}{T_{gas,in} - T_{air,in}}$$

**Obtain data from experiments in 3 operating points**

**Use ε-NTU method to calculate UA**

$$NTU = ln\left(\frac{\varepsilon - 1}{C_r\varepsilon - 1}\right)/(C_r - 1)$$

$$UA = NTU \cdot C_{min}$$

$$^{*}C_r = \frac{C_{min}}{C_{max}} = \frac{\dot{m}_{air}C_{p,cold}}{\dot{m}_{gas}C_{p,hot}}$$

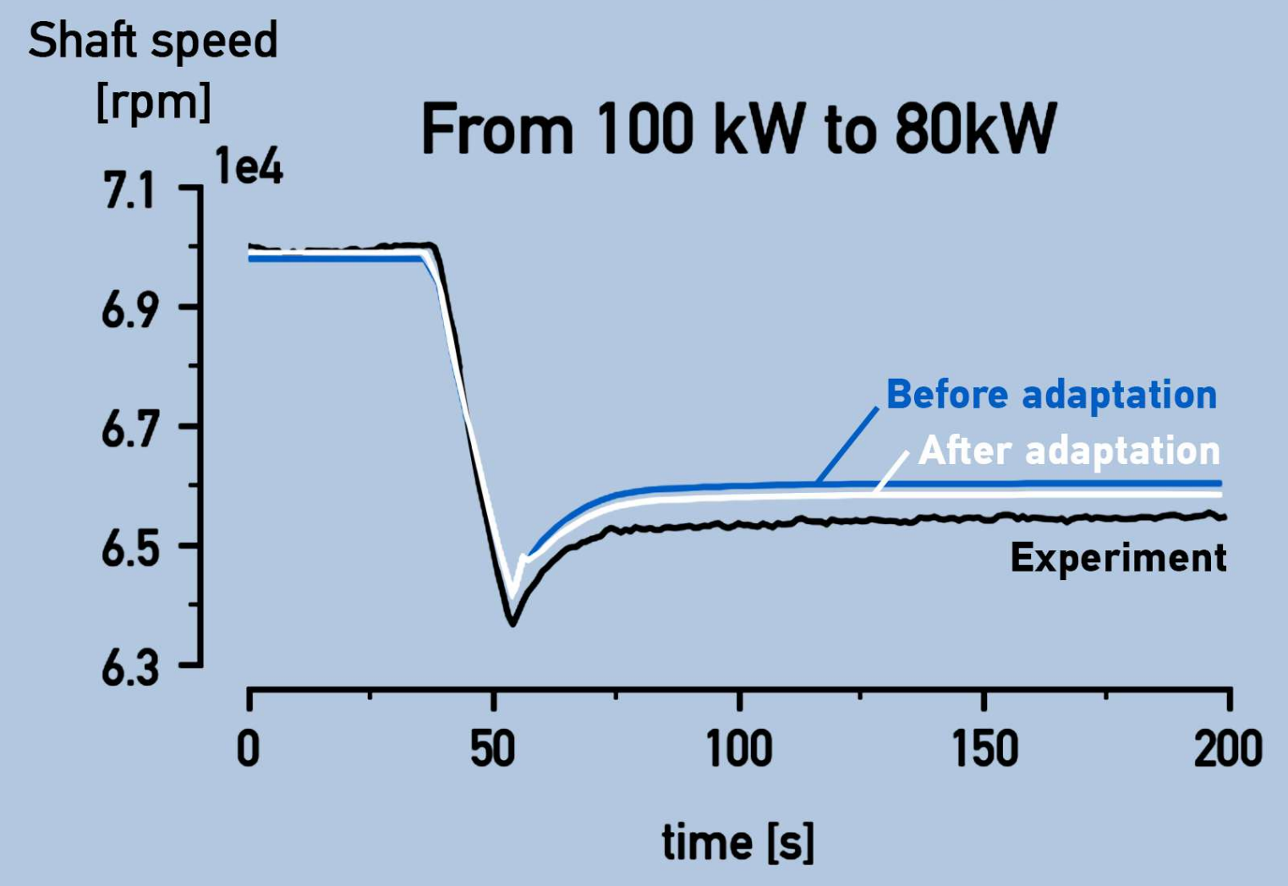
Define UA as a function of corrected mass-flow with a linear interpolation between the calculated UA from experiments

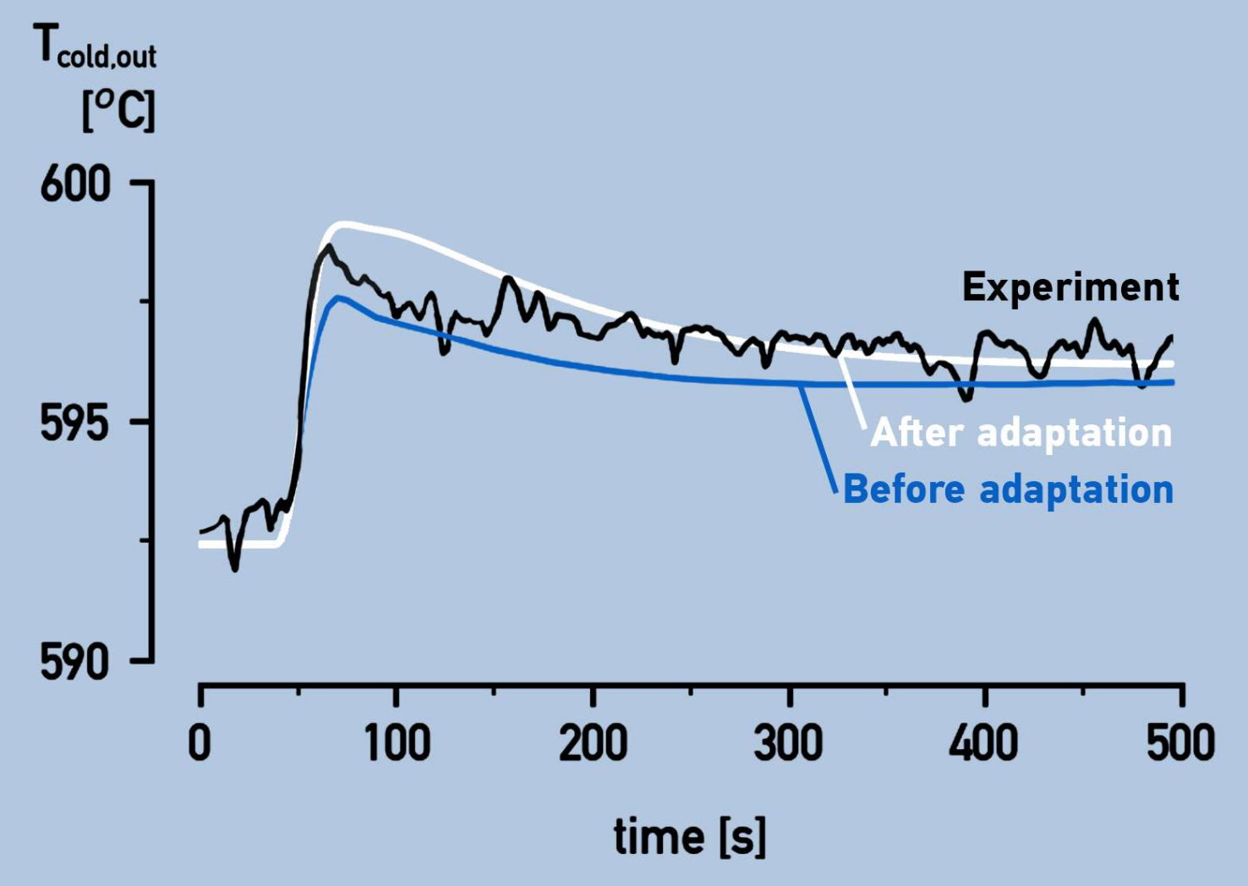
$$UA = f\left(\dot{m}\right)$$

## Preliminary dynamic results

The described methods are included in the dynamic model of mGT. Then the behaviour of specific parameters are compared with results from **experiments** and with the **simulation before the adaptation**. **Before the adaptation** the model used a **constant UA value** and a **constant isentropic efficiency** for both compressor and turbine. It also assumed a choked turbine in all operating points.

The rotational speed is related to the pressure of the system by the maps. The initial and final value of shaft speed show closer values to the experiment compared with the model before. This can be deduced as the model **before the adaptation** presents larger average error **(0.595%)** than the model **after adaptation (0.39%)**





The dynamic simulation is significantly influenced by the control system which is implemented in the model. However, another crucial element for the correct dynamic prediction of recuperator's performance is U. After the addition of variable UA, the model shows smaller deviation from experiments.

## Future work

- Tune the perfomance map parameters to match the actual T100 of the lab
- Test the effectiveness of the map adaptation method to other mGT engines
- Determine the impact of performance parameters on the compressor surge margin

## References

[1] Lagerström, G., Xie, M. (2002). High Performance & Cost Effective Recuperator for Micro-Gas Turbines. Proceedings of: ASME TURBO EXPO 2002, pp. 1003-1007.
[2] Tsoutsanis, E., Meskin, N., Benammar M., Khorasani, K. (2015). Transient Gas Turbine Performance Diagnostics Through Nonlinear Adaptation of Compressor and Turbine Maps. Journal of Engineering for Gas Turbines and Power, 137(9).

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