EXTRAPOLABILITY AND LIMITATIONS OF A SEMI-EMPIRICAL MODEL FOR CHARACTERIZING VOLUMETRIC EXPANDERS

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Introduction

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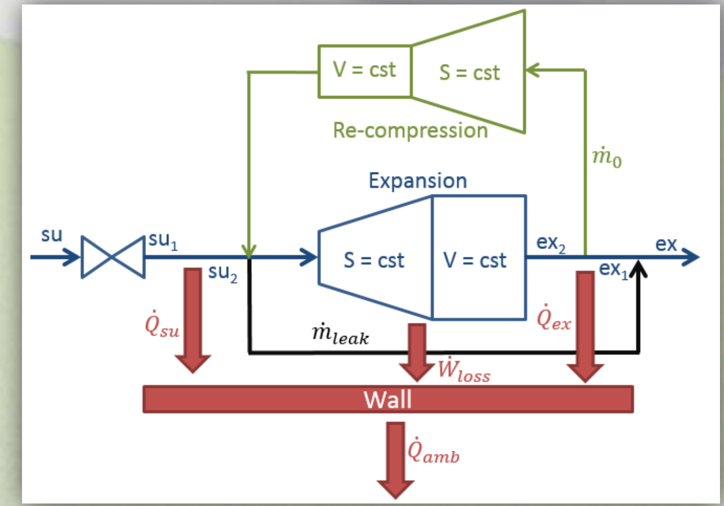


Introduction
Semi-empirical model

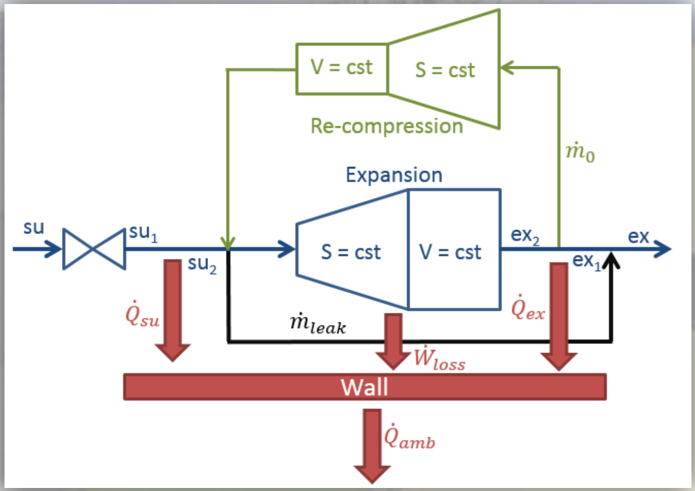
Exchanger, pump, compressor, expander…

Fast CPU time

Robust

Extrapolability via physical law

Good fitness with experiment



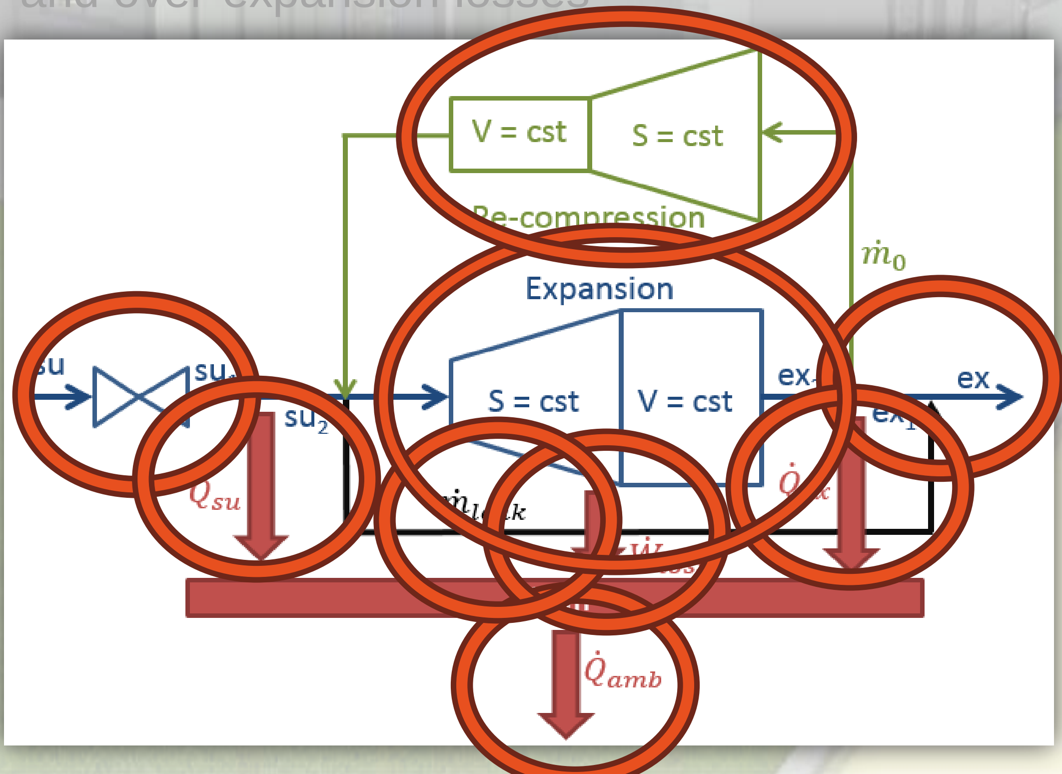
Not deterministic ➔ require a database

Lumped parameters ➔ miss some physical effects

Which limit for extrapolability?

Introduction
Volumetric expander semi-empirical model

- Same formalism for each technology
- Several level of details possible
  - Pressure drop (supply+exaust)
  - Heat transfers (ambient, supply, exhaust)
  - Mechanical losses (constant, proportional)
  - Leakages
  - Under and over-expansion losses



Introduction
Volumetric expander semi-empirical model

- Inputs
- Parameters
- Outputs

Inputs	Calibration parameters	Outputs
Volume ratio	Supply nozzle equivalent diameter	Shaft power [W]
Swept volume	Supply heat transfer coefficient	Mass flow rate [kg/s]
Inlet temperature	Exhaust heat transfer coefficient	Outlet temperature [°C]
Inlet pressure	Ambient heat transfer coefficient	
Outlet pressure	Equivalent leakage area	
Rotational speed	Proportional mechanical losses	
Ambient temperature	Constant mechanical losses	
	Clearance volume	

$$Err = \sum_i \left(\left(\frac{\dot{m}_{meas,i} - \dot{m}_{pred,i}}{\dot{m}_{meas,i}} \right)^2 + \left(\frac{T_{meas,i} - T_{pred,i}}{\max(T_{meas}) - \min(T_{meas})} \right)^2 + \left(\frac{\dot{W}_{sh,meas,i} - \dot{W}_{sh,pred,i}}{\dot{W}_{sh,meas,i}} \right)^2 \right)$$

Introduction

Limitations

- High pressure ratio and shaft speed often absent of the database
  - Test-rig limitations (pump, pressure drops…)
  - Time
  - Narrow Matrix of tests

- What about extrapolation outside of the dataset?

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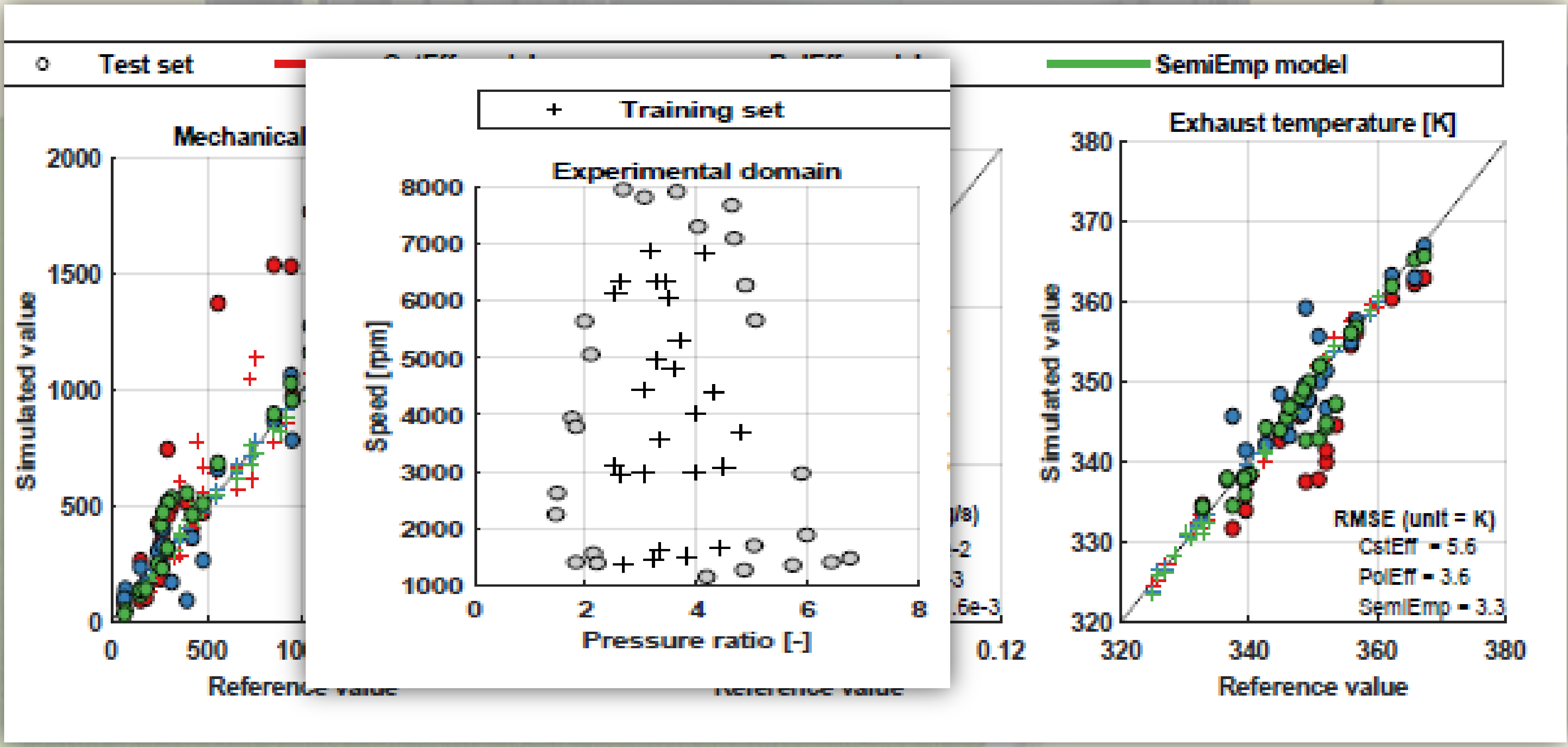
Methodology

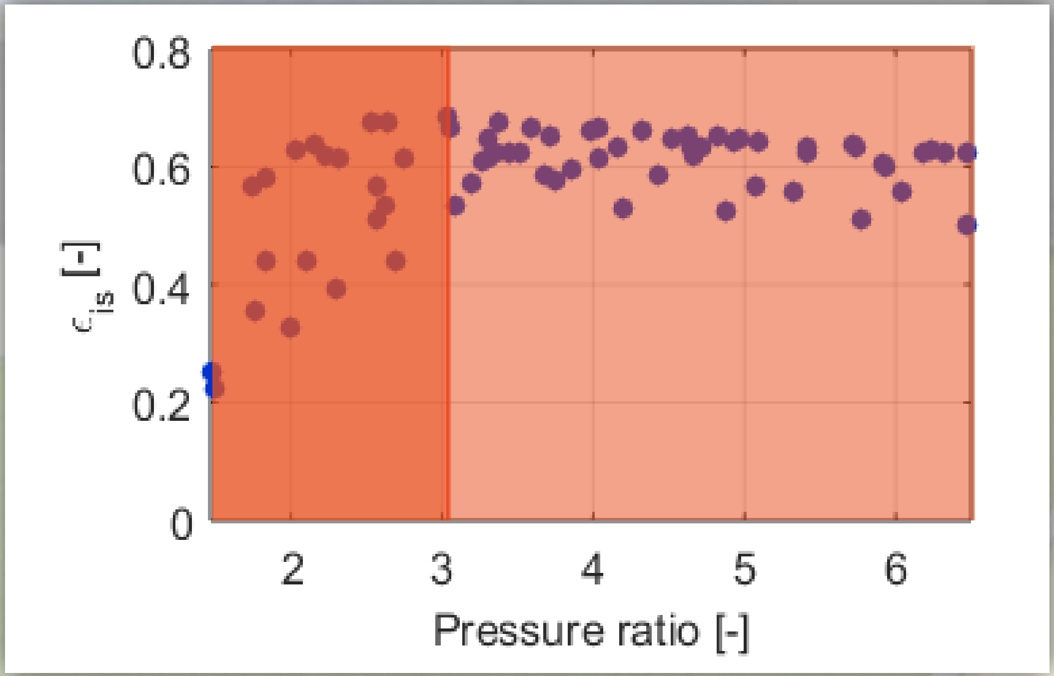
State of the art (Dickes et al, 2016)

- Extrapolation trough convex hull
  - Calibration set
  - Extrapolation set
- Acceptable accuracy in extrapolation BUT extrapolation in extreme point
- ➔more realistic to define the training set with low RP and N



Methodology
Proposed methodology

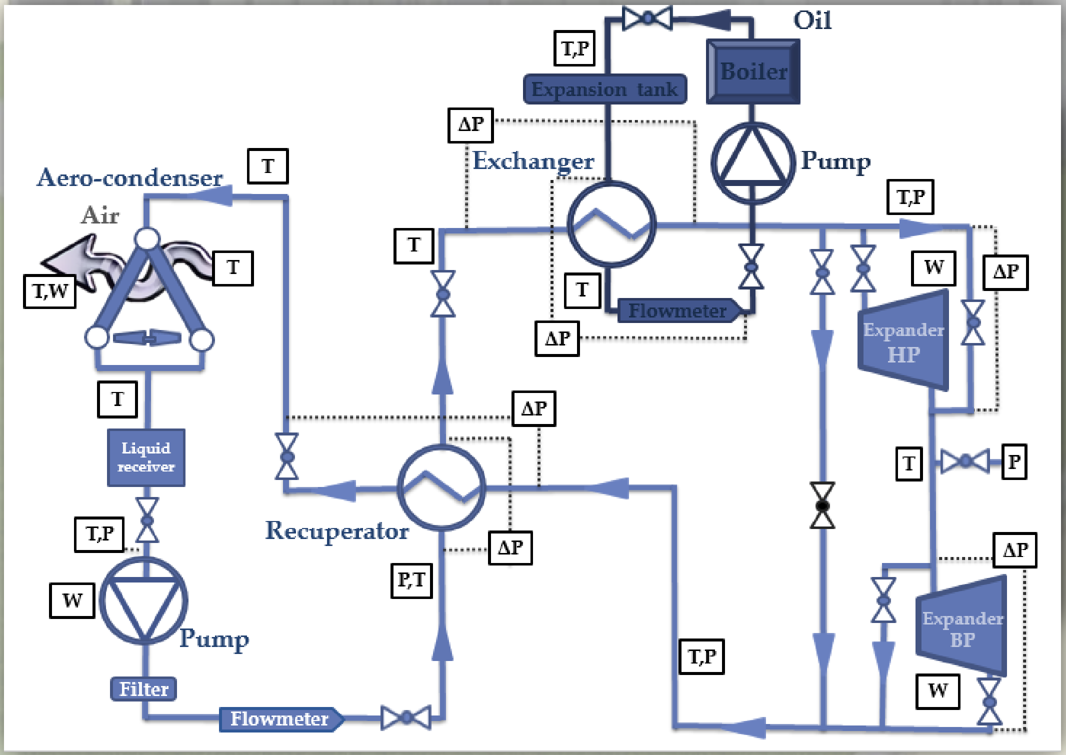
1. Definition of a training set (fraction of RP or N)
2. Calibration of the parameters with the training set
3. Evaluation of the Mean Average Error (MAE) on the full database



$$MAE = \frac{\sum_{i=0}^{N} |\bar{y}_i - y_i|}{N}$$

Methodology
Study case - expander

- Variable speed hermetic scroll modified compressor
  - Refrigerant R245fa + 5% oil
  - Swept volume is 12.74 cm^3
  - Volume ratio is 2.19
  - Power ~ 1 kW (connected to an electrical load)
  - Shaft speed [1000:6000] RPM



SUN2POWER

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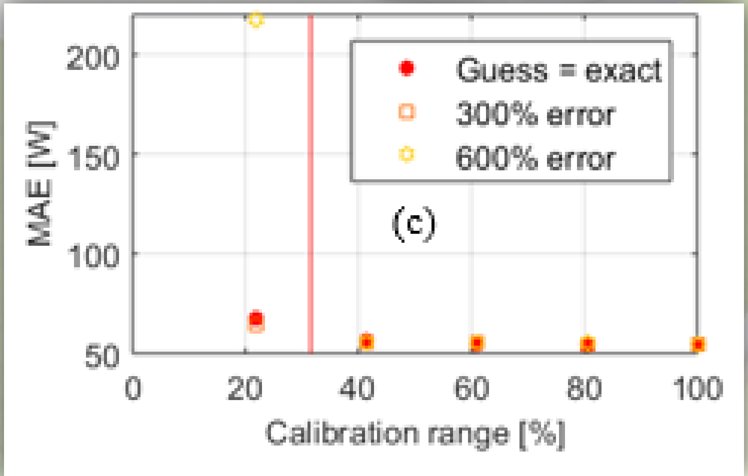
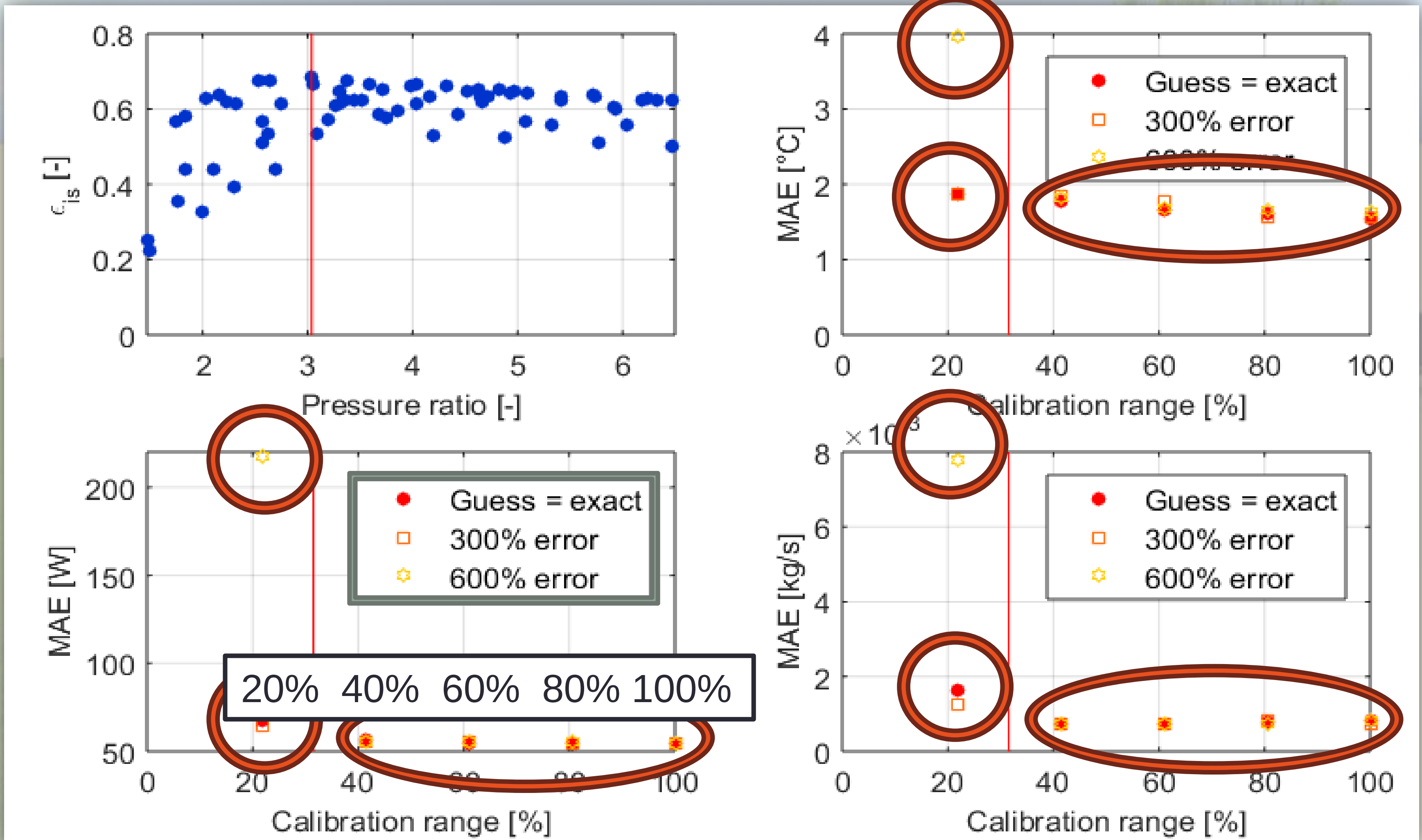


Results

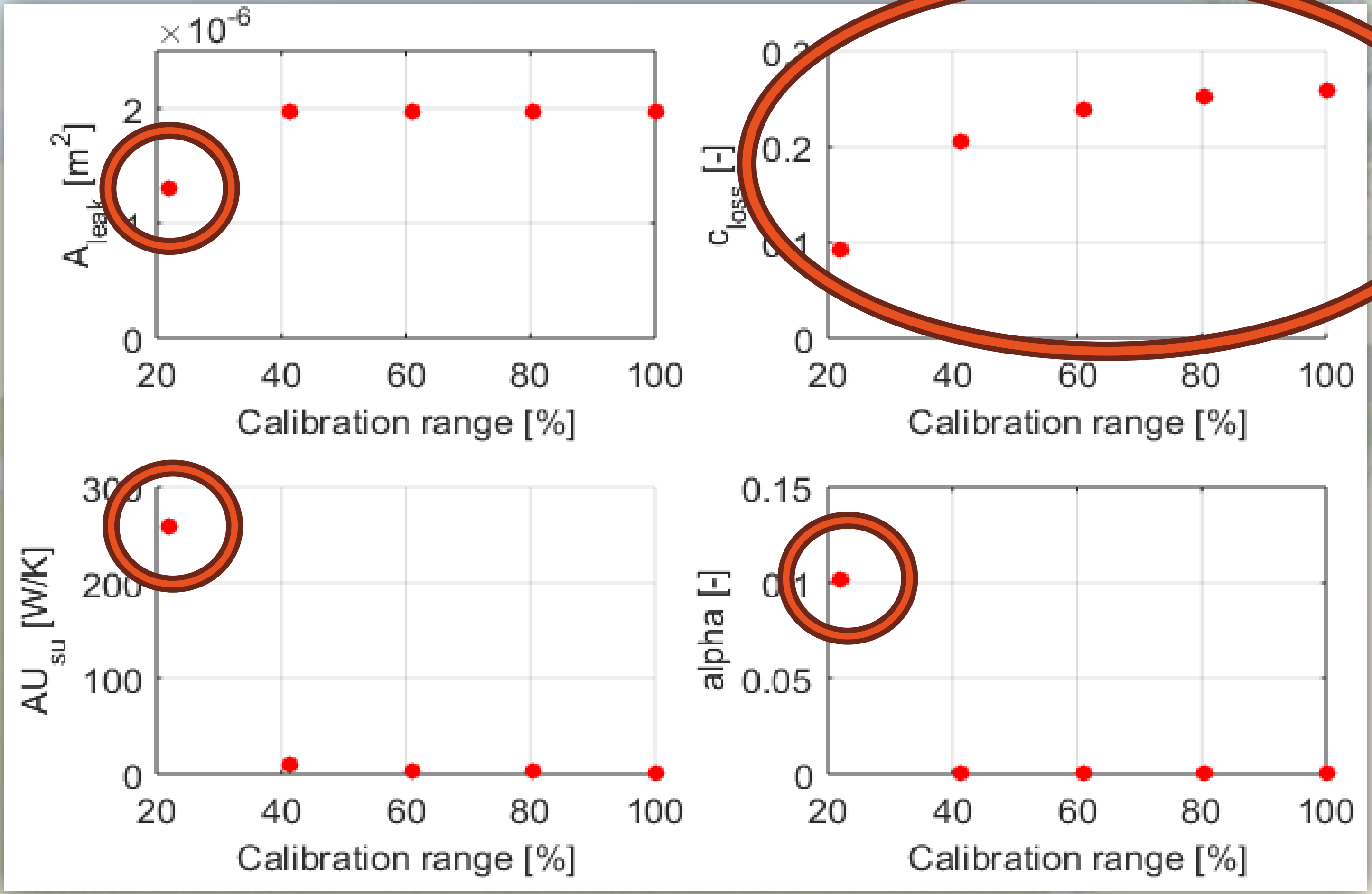
Pressure ratio



- Good extrapolation except with huge error on the guess

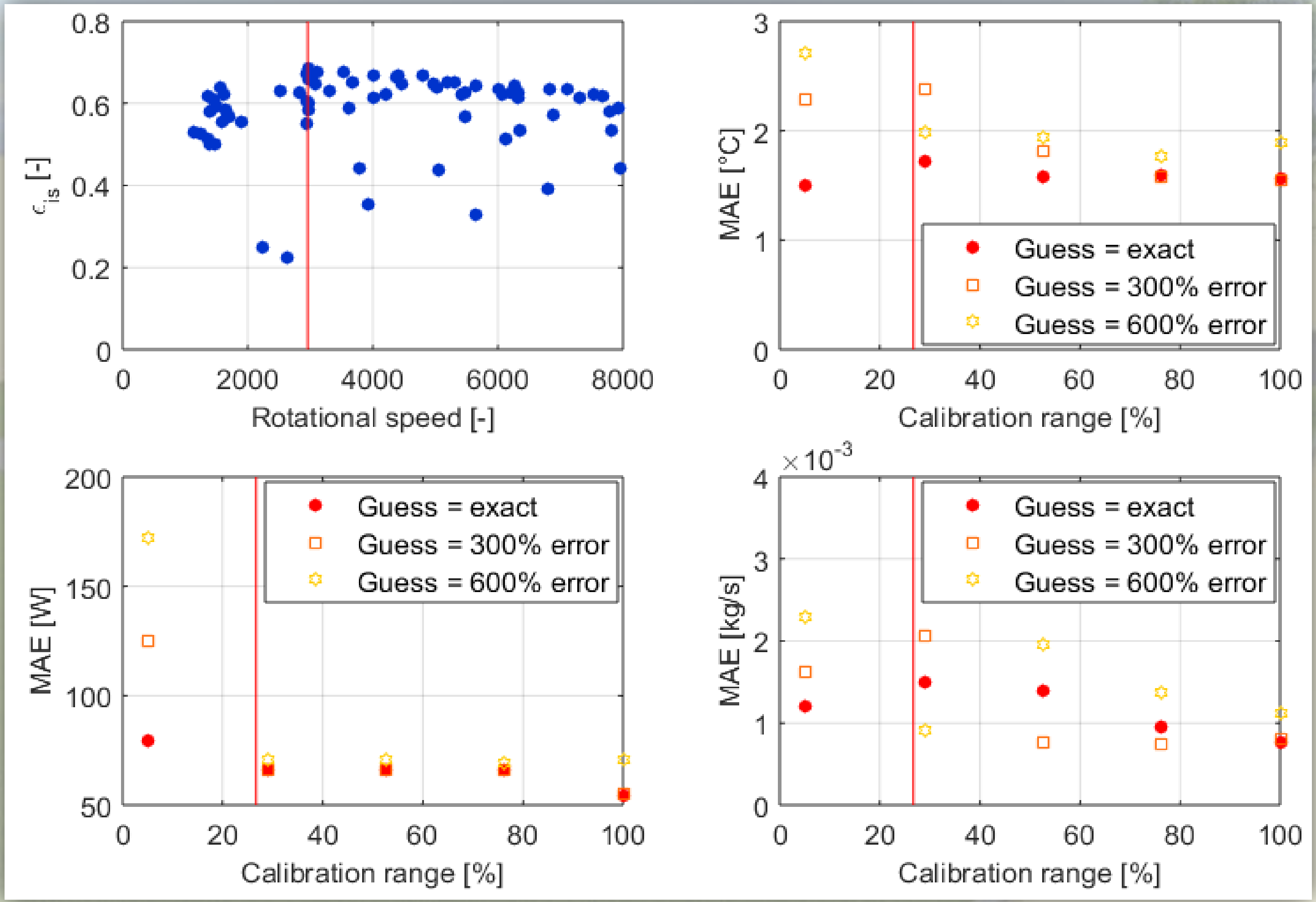
Results

Calibration parameters



- Local minima!

Results
Shaft speed



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Discussion
Guidelines

1. Try to get the largest ranges of operating conditions in experimentation
2. Optimization algorythm unsensible to local minima should be used
3. Good extrapolation for data containing the maximum of isentropic efficiency
4. Selection of a sufficiently accurate initial guess fro algorithm is important
   1. Litterature
   2. Rough calibration with low number of parameter

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Conclusion

- Preliminary study to characterize extrapolation of volumetric expander semi-empirical model
  - 41% of the maximum pressure ratio sufficient to get an extrapolation MAE lower than 10%.
  - 27% of the maximum shaft speed sufficient to get an extrapolation MAE lower than 10%.

- Perspectives
  - Other expanders
    - Power range
    - Technology
  - Fluids
  - Optimization function
  - Exchangers, pumps, compressors…

Thank you!

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