Competence Center for Gas Exchange

CCGEx

KTH VETENSKAP OCH KONST

”Charging for the future”

Energimyndigheten SCANIA VOLVO BorgWarner

KTH ROYAL INSTITUTE
OF TECHNOLOGY

Flow Exergy Analysis of a Turbocharger Radial Turbine

Shyang Maw Lim
Supervisors: Mihai Mihaescu, Anders Dahlkild,
Christophe Duwig, Laszlo Fuchs

Research Questions

- How the turbine performance (e.g. pressure ratio, power) affected by heat transfer?
- What are the mechanisms of heat transfer related losses and how can we quantify them?
- How the upstream exhaust manifolds and flow instabilities affect heat transfer and turbine performance?
- How different exhaust valve strategies affects the heat transfer and turbine performance?

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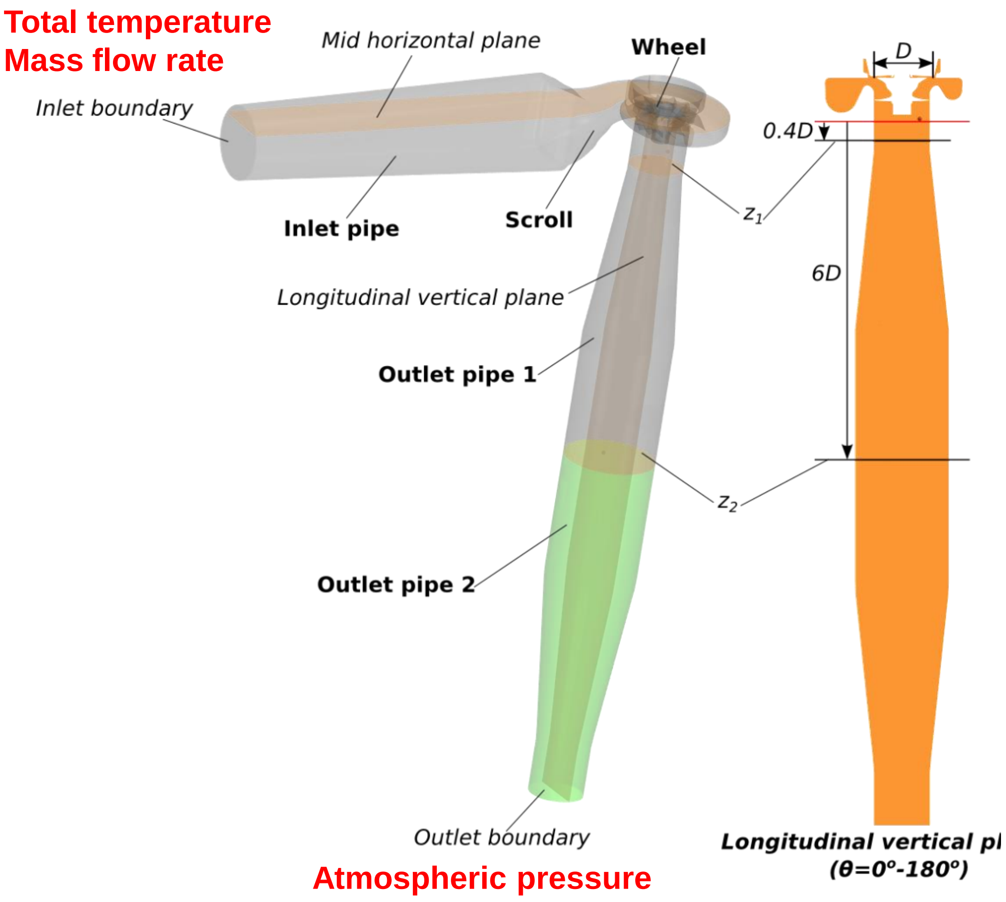
today's topics with selective results

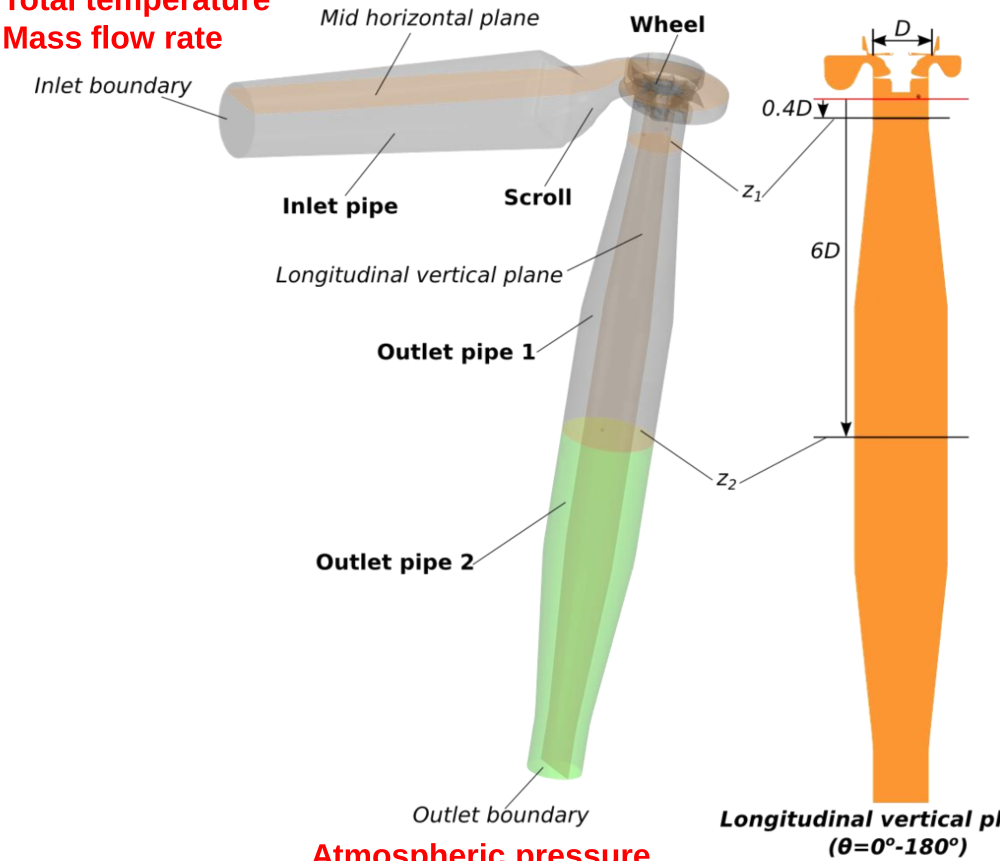
- How the upstream exhaust manifolds and flow instabilities affect heat transfer and turbine performance?
- How different exhaust valve strategies affects the heat transfer and turbine performance?

Computational Setup



Computational Setup

Total temperature
Mass flow rate



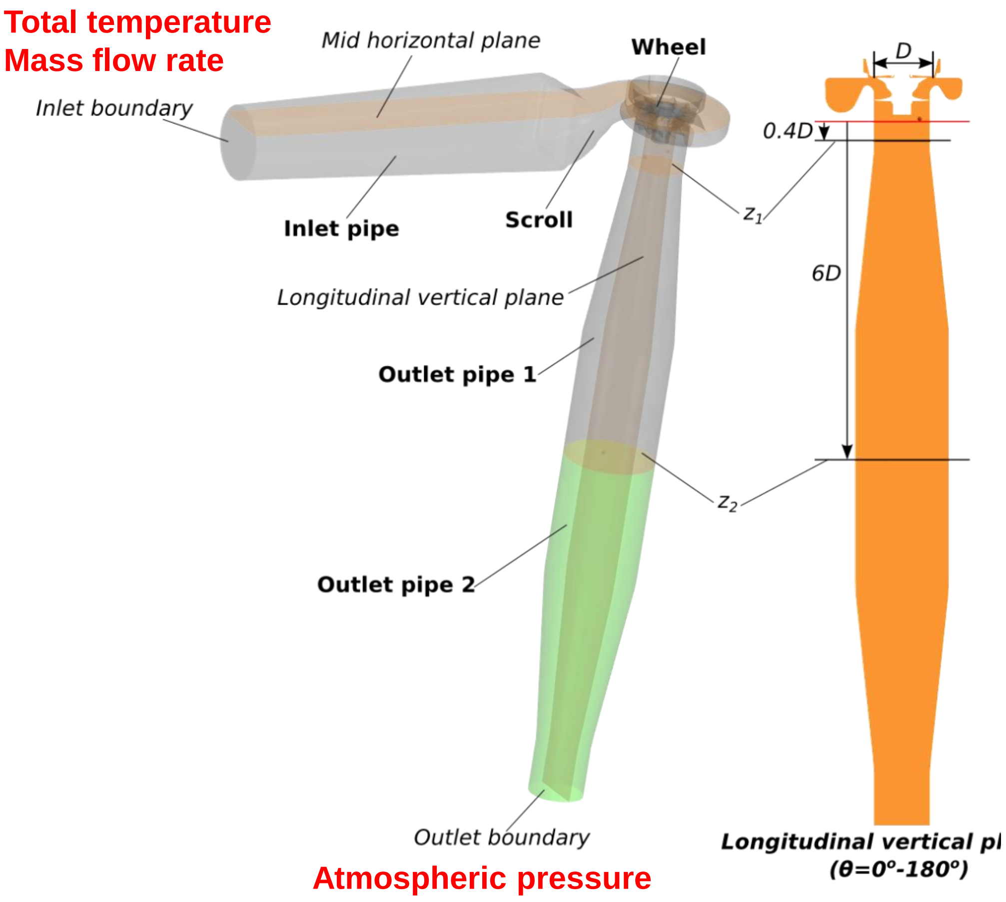
Atmospheric pressure

Wall thermal condition:

- Adiabatic
- Constant temperatures
  T_w [K]=1002

estimated from experimental data of Romagnoli & Martinez-Botas (2012)

Computational Setup



Wall thermal condition:

- ❑ Adiabatic
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  T_w [K]=<u>1002</u>, 830, 487

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Computational Setup

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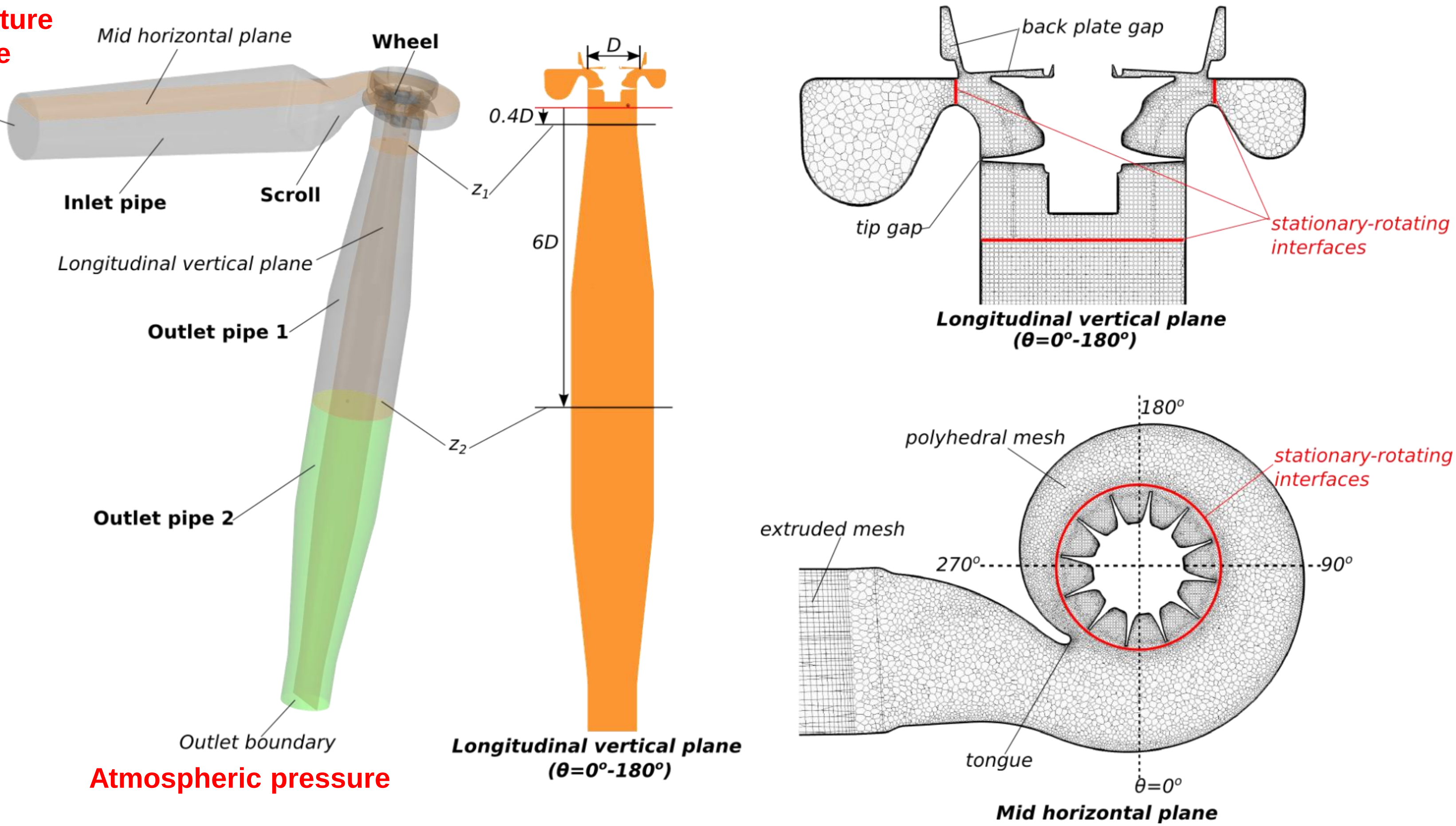
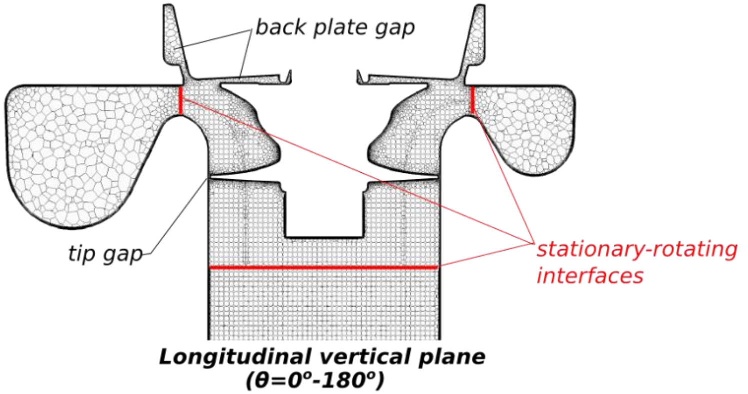
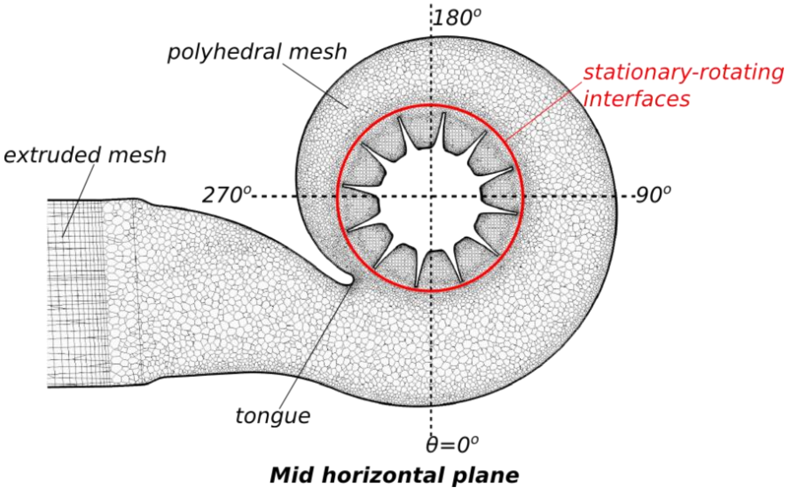


Atmospheric pressure

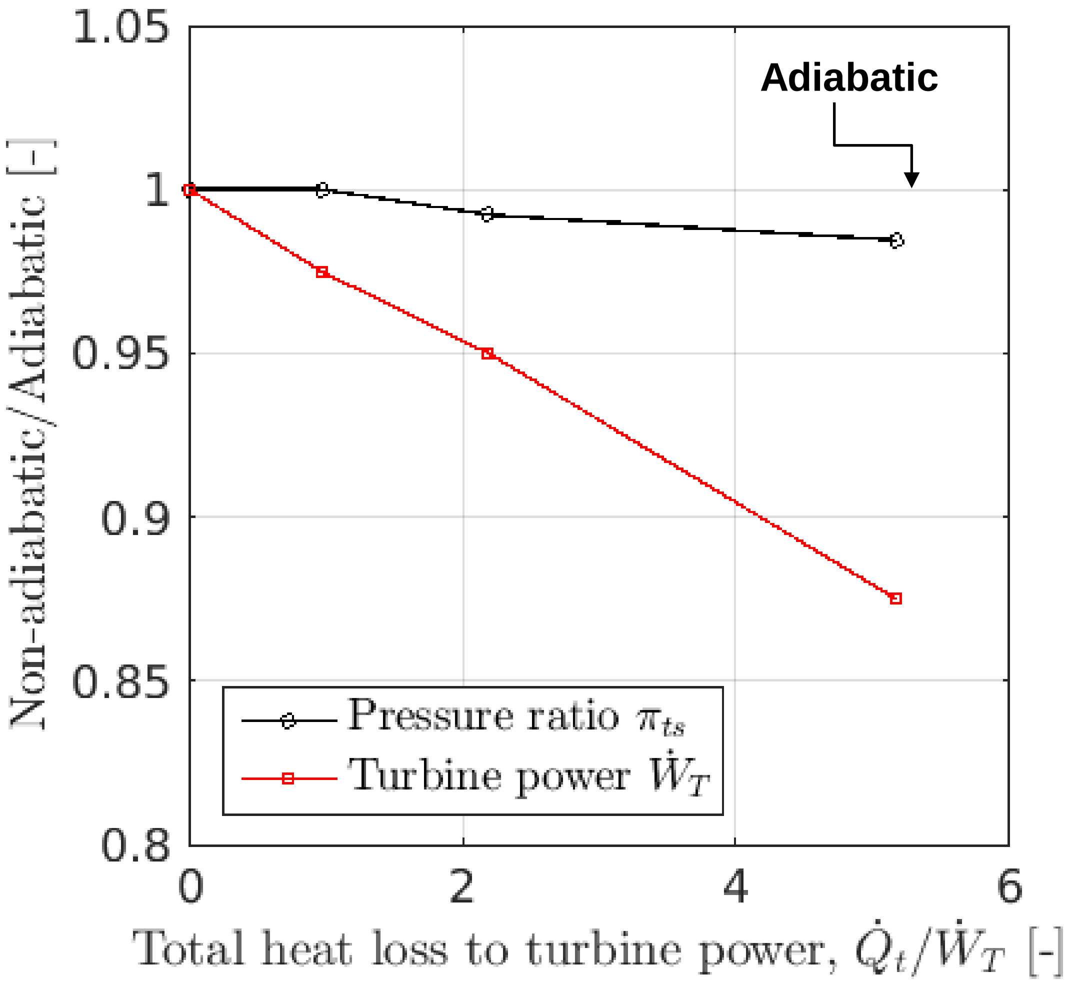
Computational Setup

- ~ 9 millions polyhedral cells
- Y+~1
- SST k-ω Detached Eddy Simulation (DES)
- Wheel rotation: Sliding mesh





Energy Balance Analysis



$$\dot{Q}_t = \sum \dot{Q}_i \qquad \dot{W}_T = \iint_{S_{wheel}} [(\vec{r} \times \vec{f}) \cdot \vec{\omega}]\, dS$$

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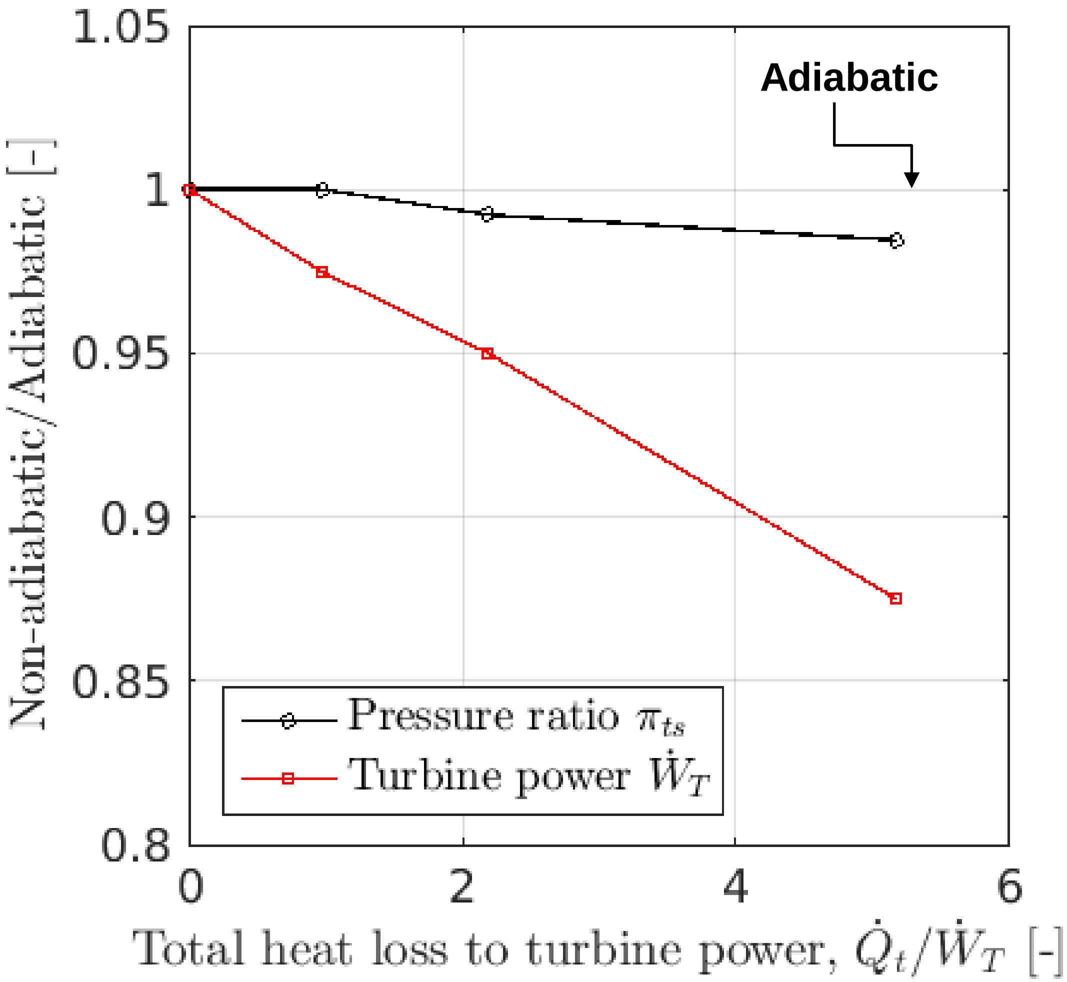

- Turbine power is sensitive to heat loss.
- Pressure ratio is relatively insensitive to heat loss.

  OBS:
  We are predicting the pressure,
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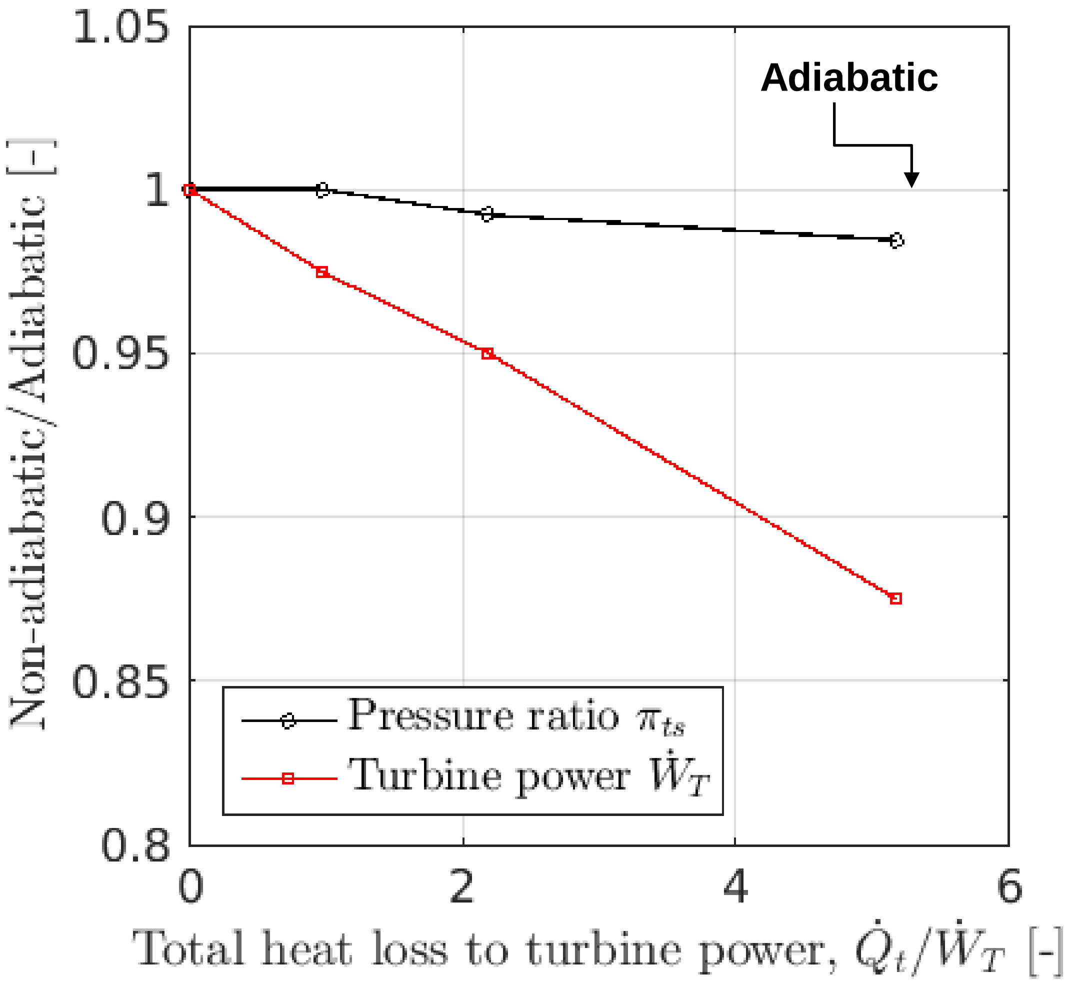

- Turbine power is sensitive to heat loss.
- Pressure ratio is relatively insensitive to heat loss.
  OBS:
  We are predicting the pressure,
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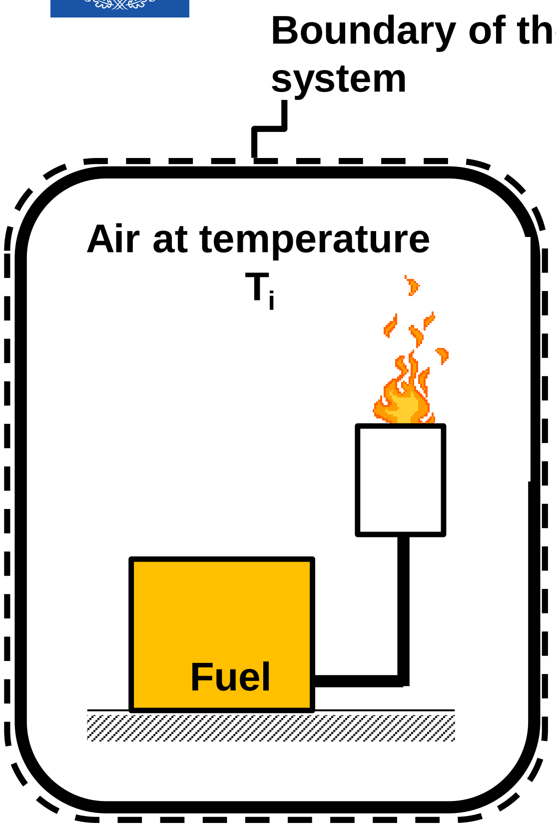
- Energy balance's drawback: unable to quantify the mechanisms of heat transfer related losses.

$$\dot{Q}_t = \sum \dot{Q}_i \qquad \dot{W}_T = \iint_{S_{wheel}} [(\vec{r} \times \vec{f}) \cdot \vec{\omega}]\, dS$$

Energy vs. Exergy



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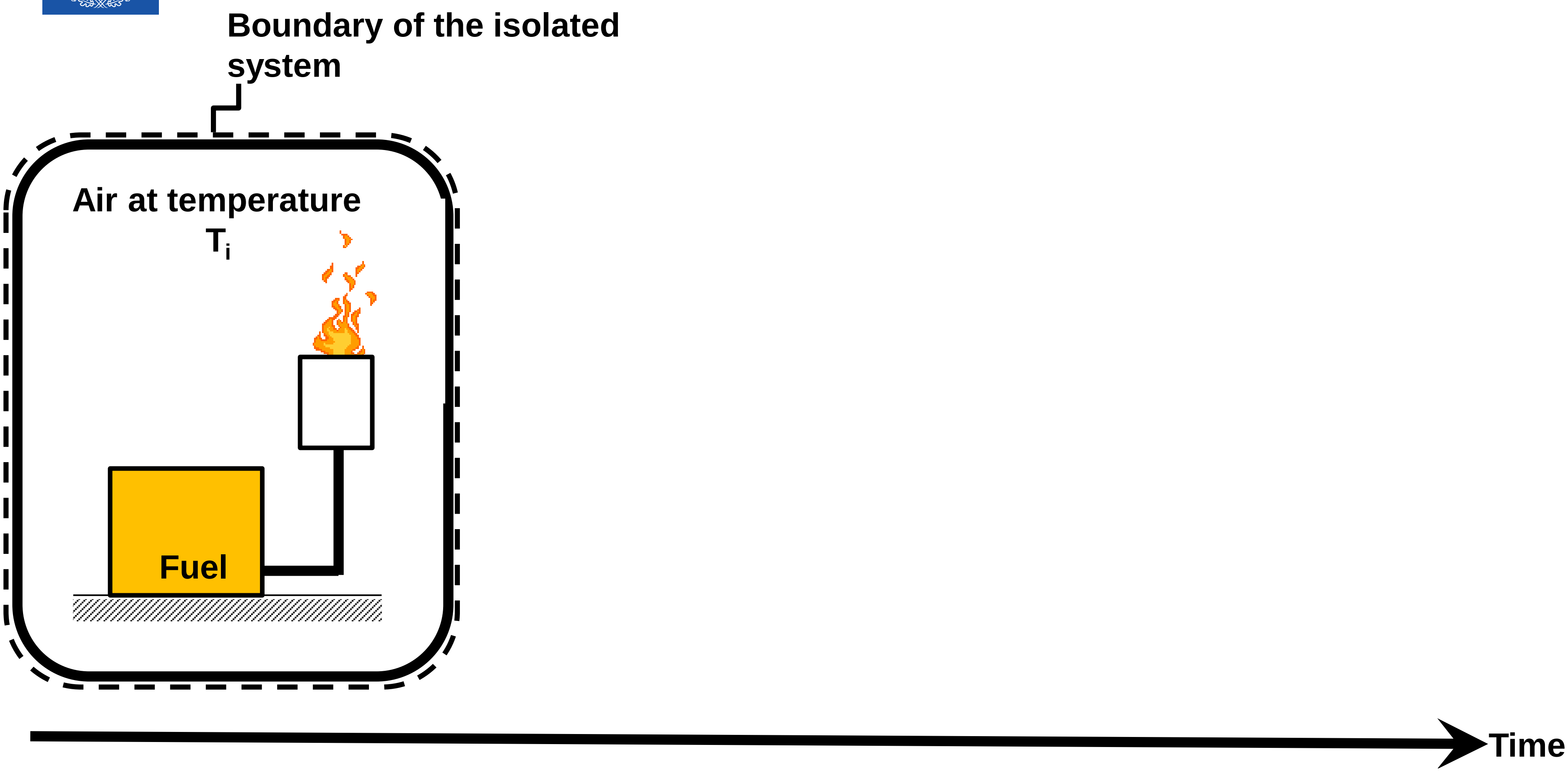

Adapted from Moran, Shapiro, Boettner, Balley,"Principles of Engineering Thermodynamics"

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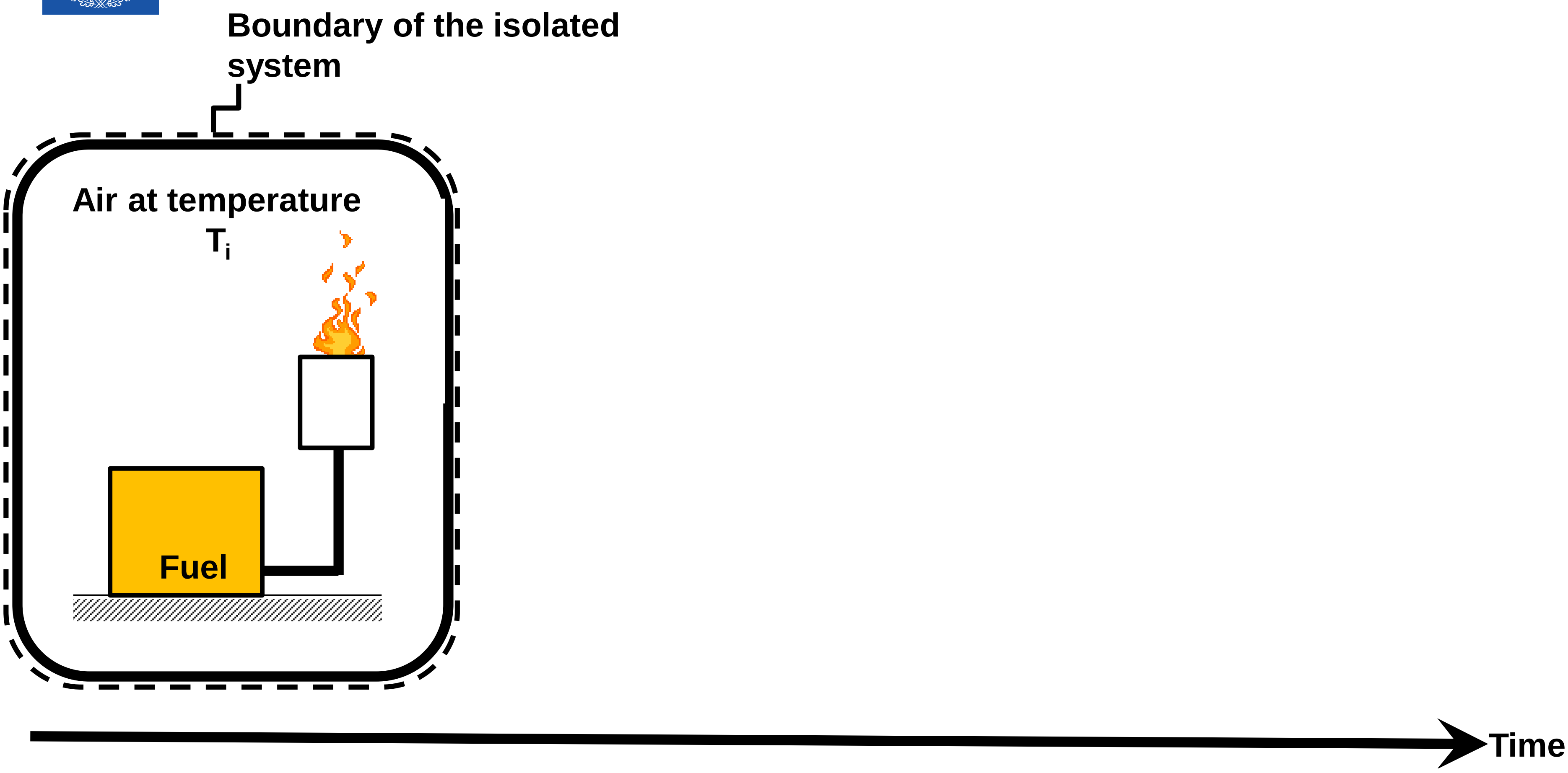

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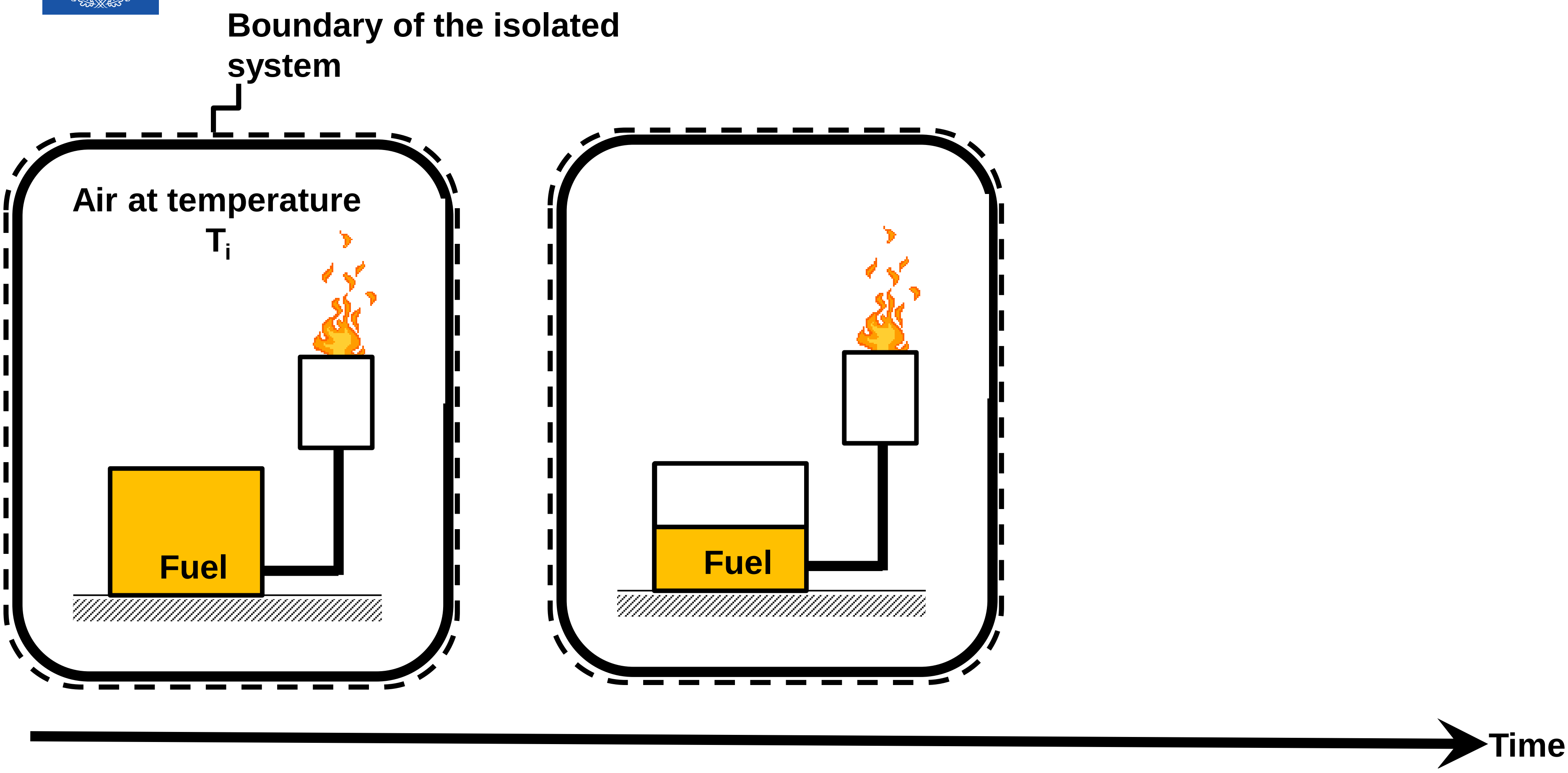

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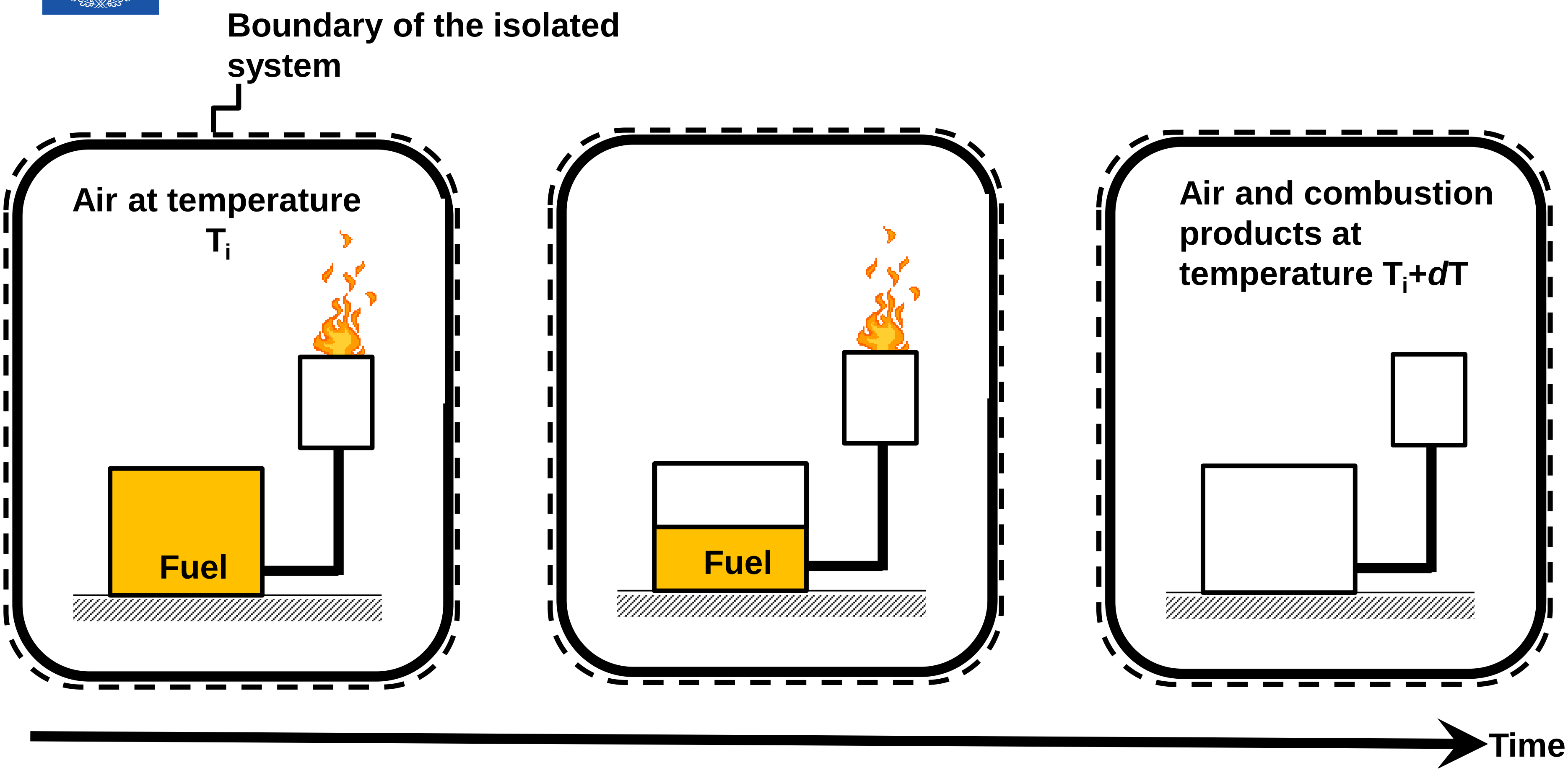

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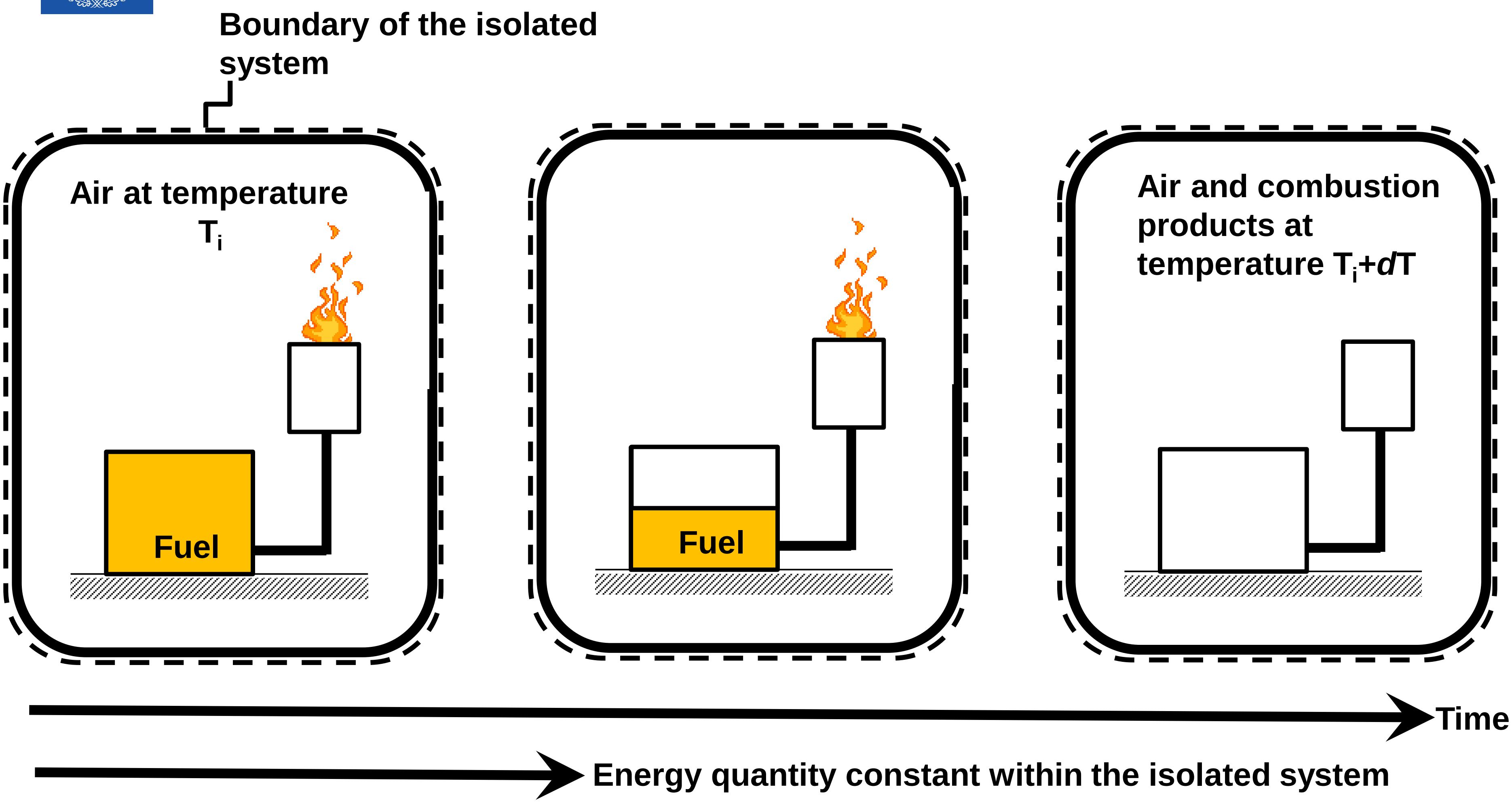

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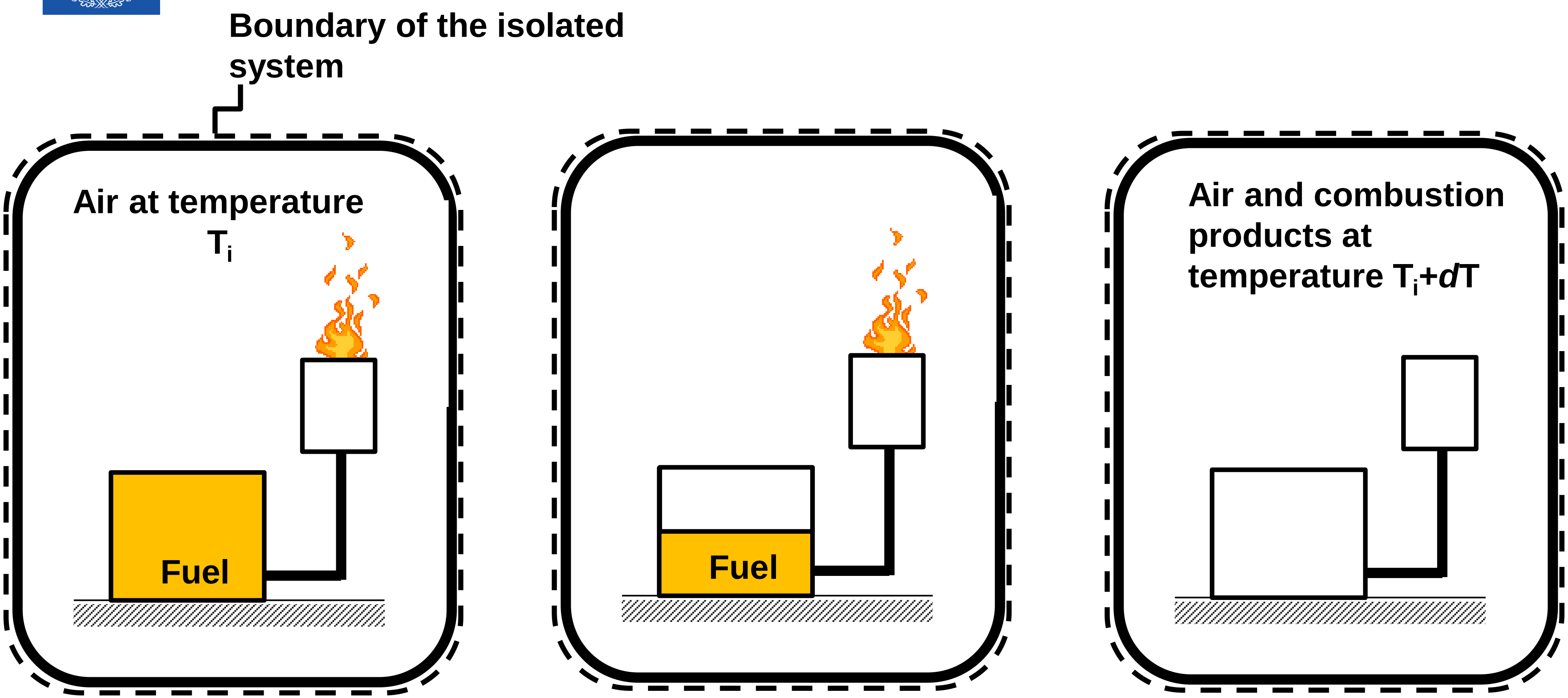

Time

Energy quantity constant within the isolated system

Potential for use (*Exergy/Availability*) decreases

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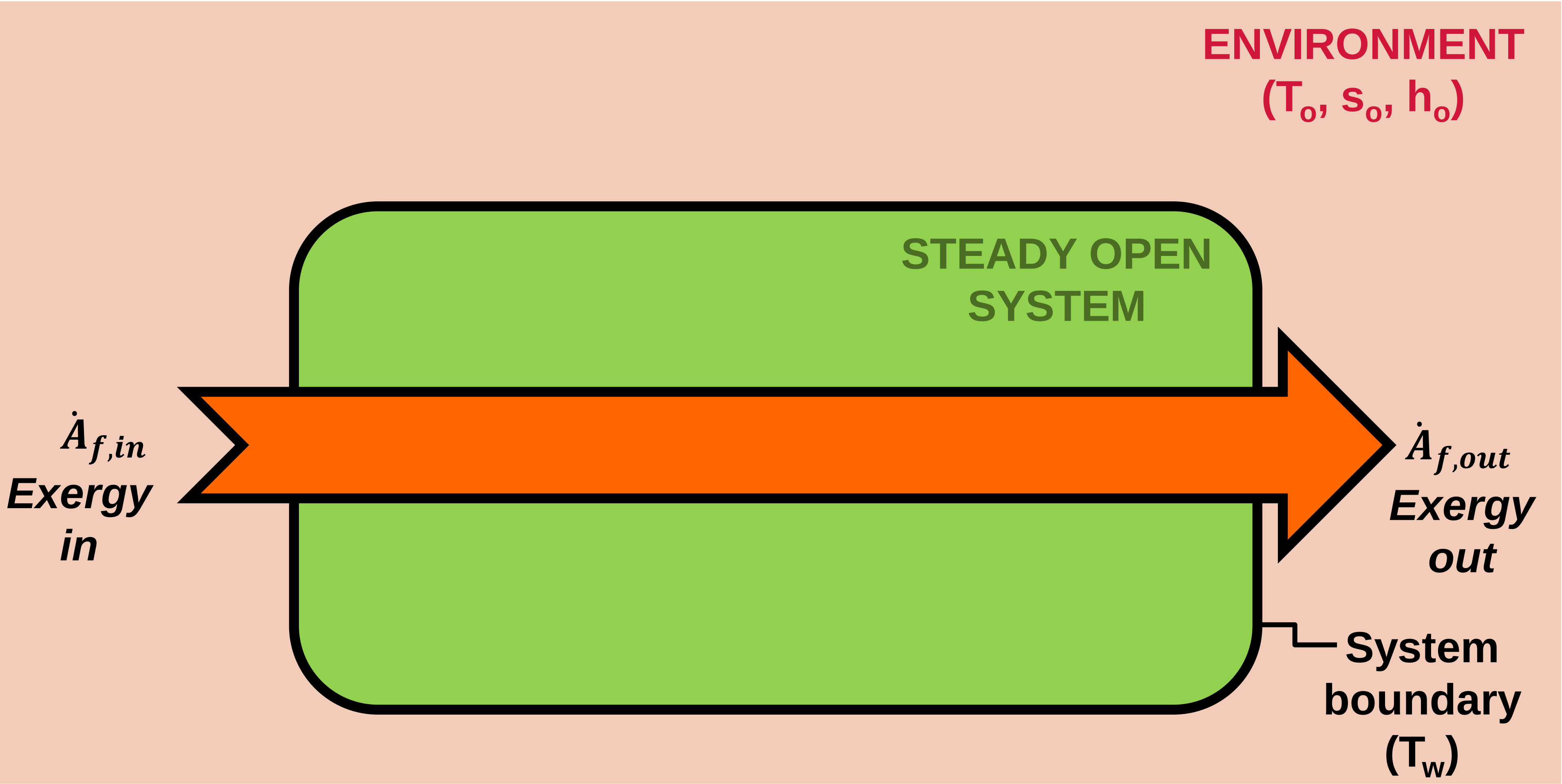
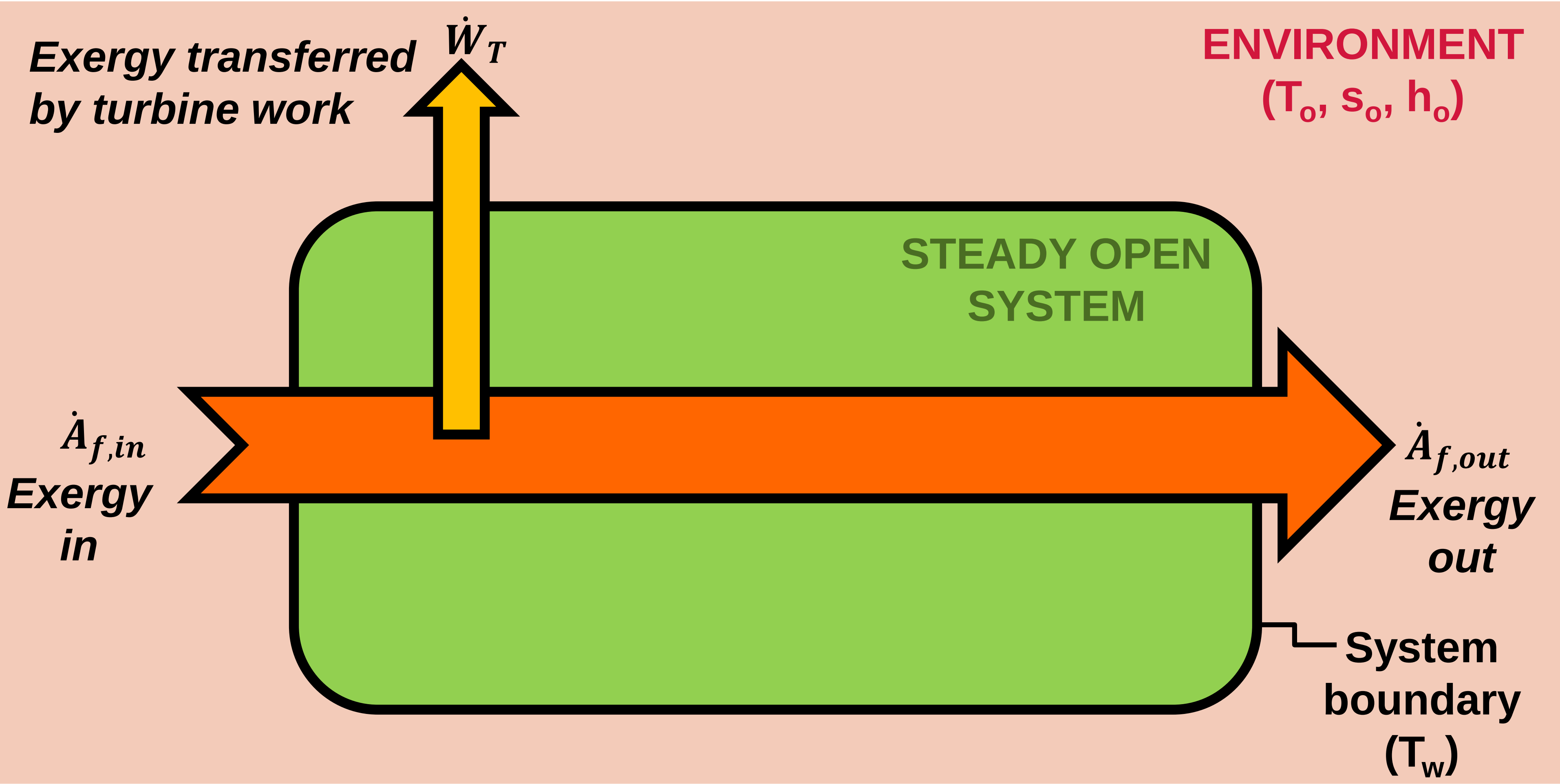
Losses Mechanisms



$$\dot{A}_f = \dot{m}\left[(h - h_o) - T_o(s - s_o) + \frac{U^2}{2}\right]$$

Losses Mechanisms



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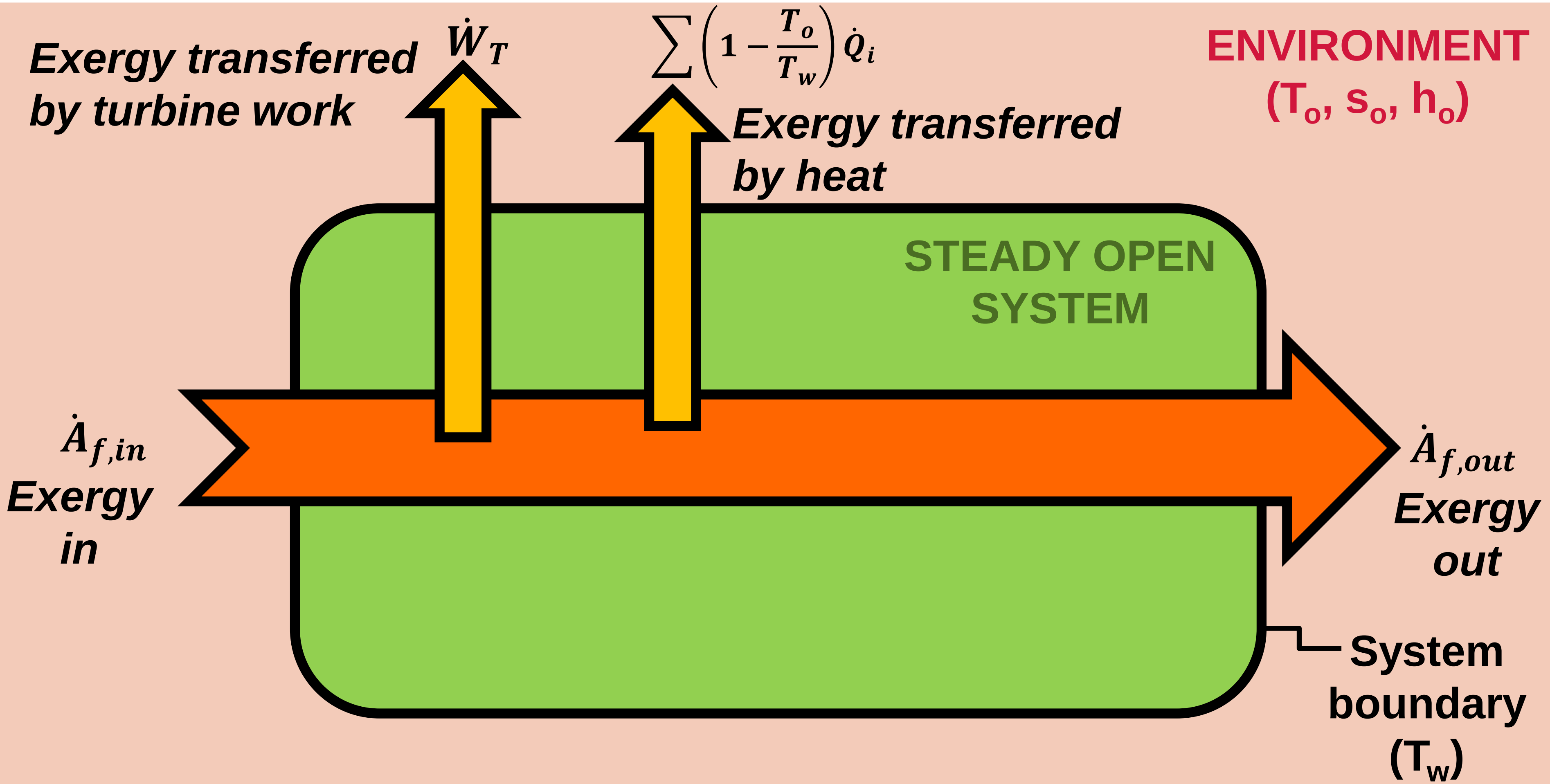

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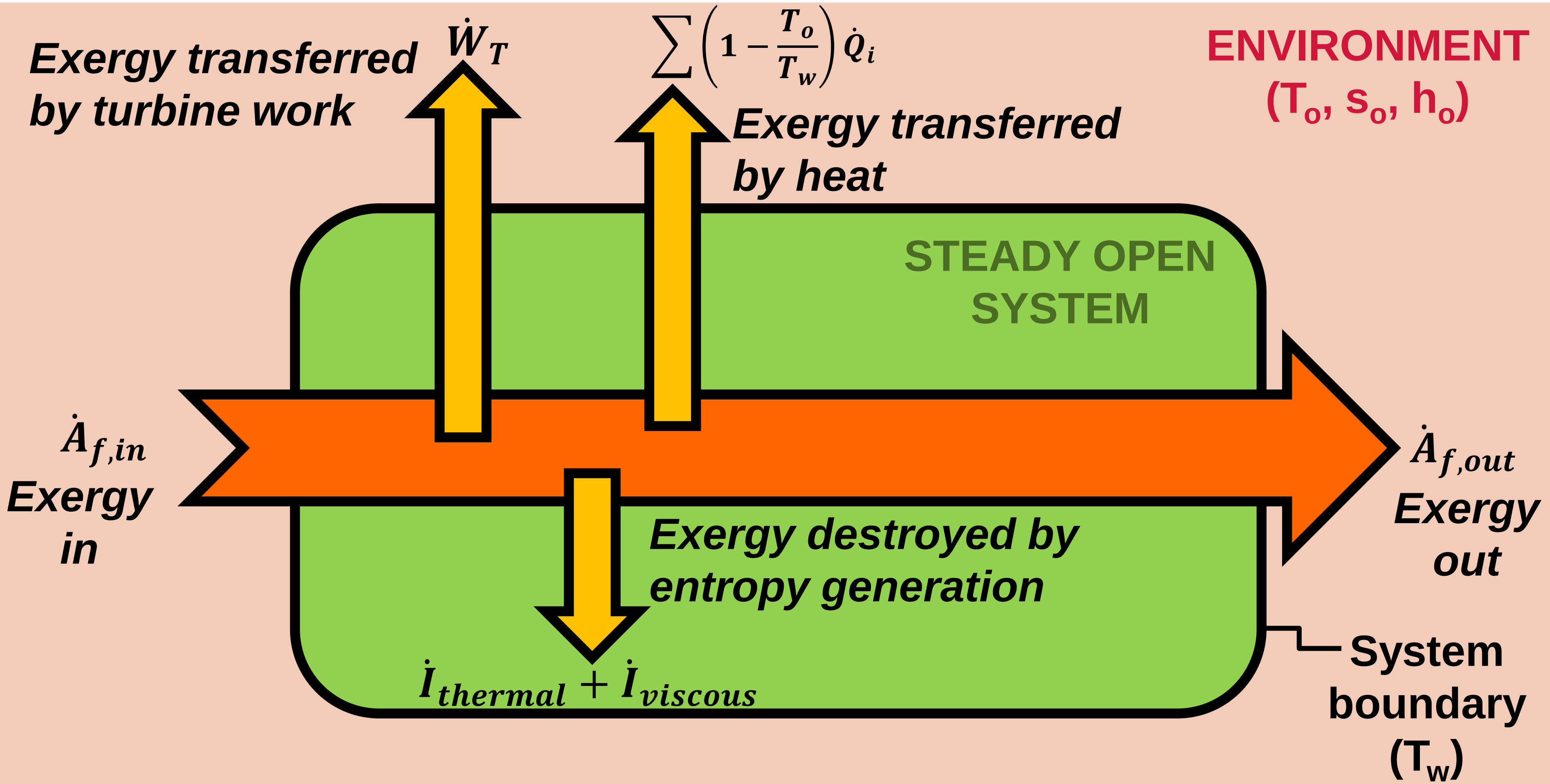

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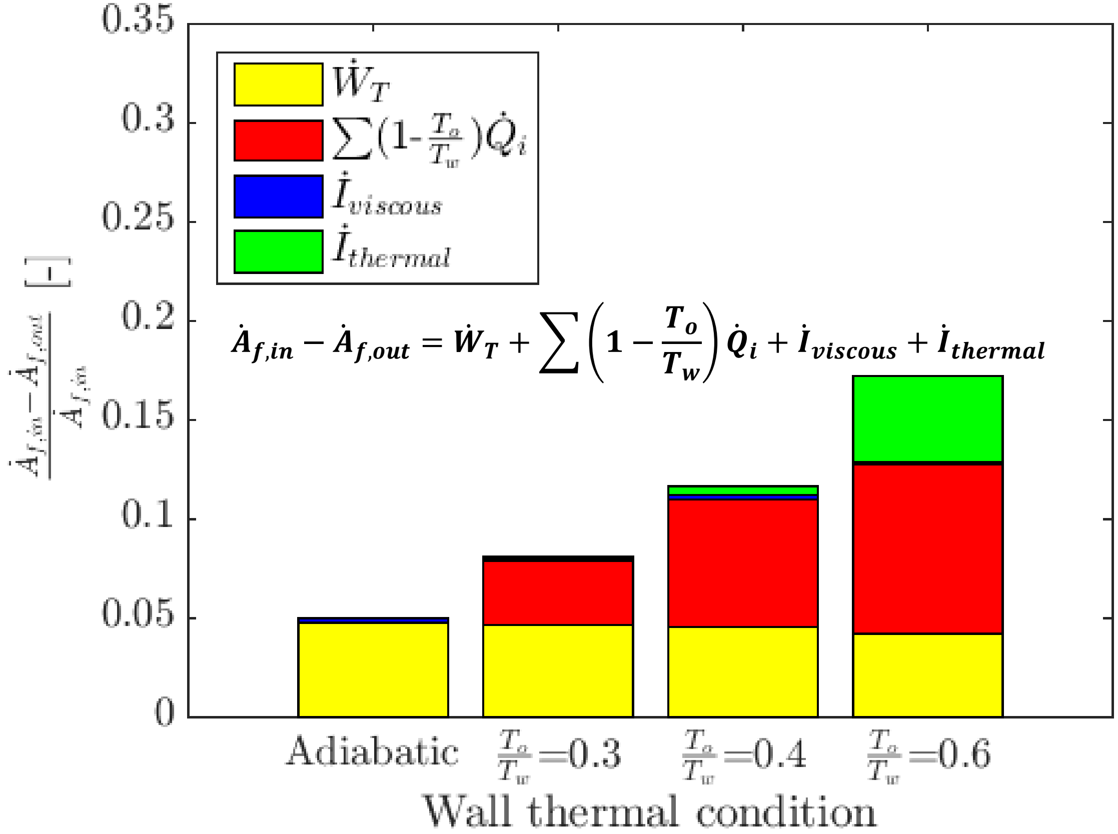
Overall Exergy Budget

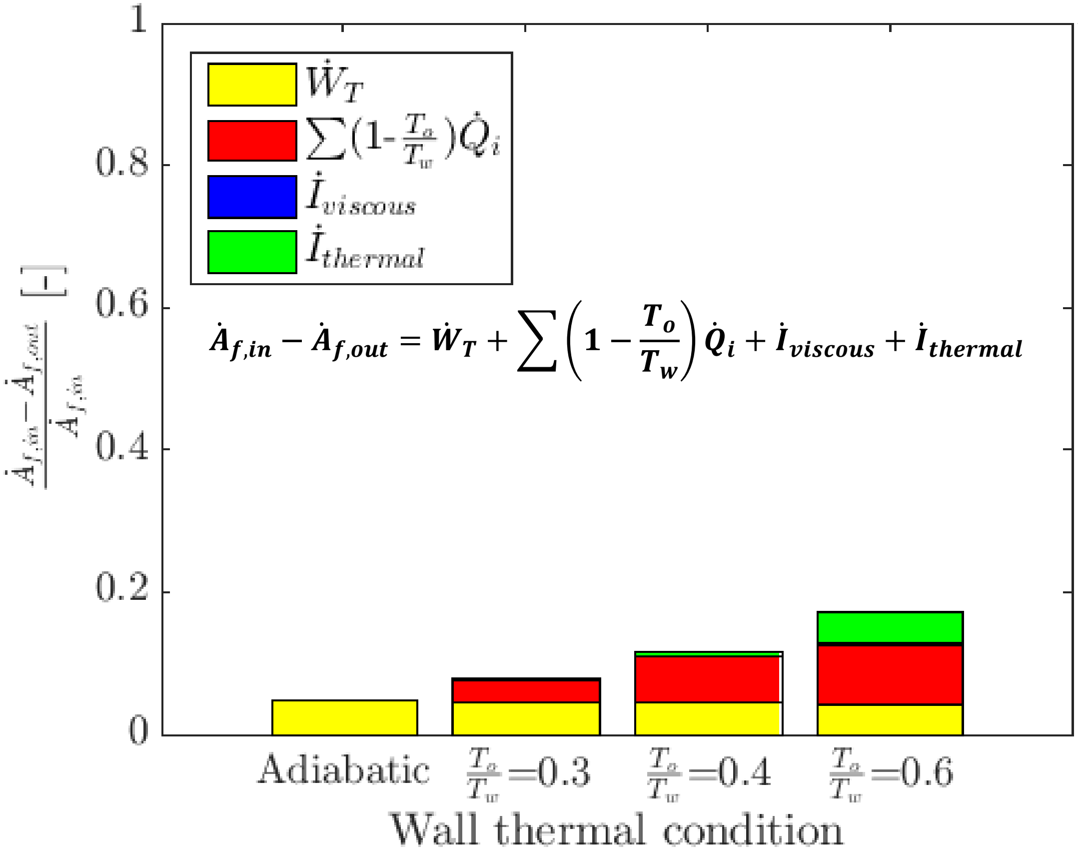


- Heat transfer decreases exergy through heat flow and thermal entropy generation.

$$\dot{Q}_i = \iint_{S_i} \vec{q} \cdot d\vec{S} \qquad \dot{I}_{thermal} = T_o \iiint_{V_{CV}} \frac{\lambda}{T^2} (\nabla T)^2 dV \qquad \dot{I}_{viscous} = T_o \iiint_{V_{cv}} \frac{1}{T} \tau_{kj} \frac{\partial u_k}{\partial x_j} dV$$

Overall Exergy Budget

Total exergy /availability



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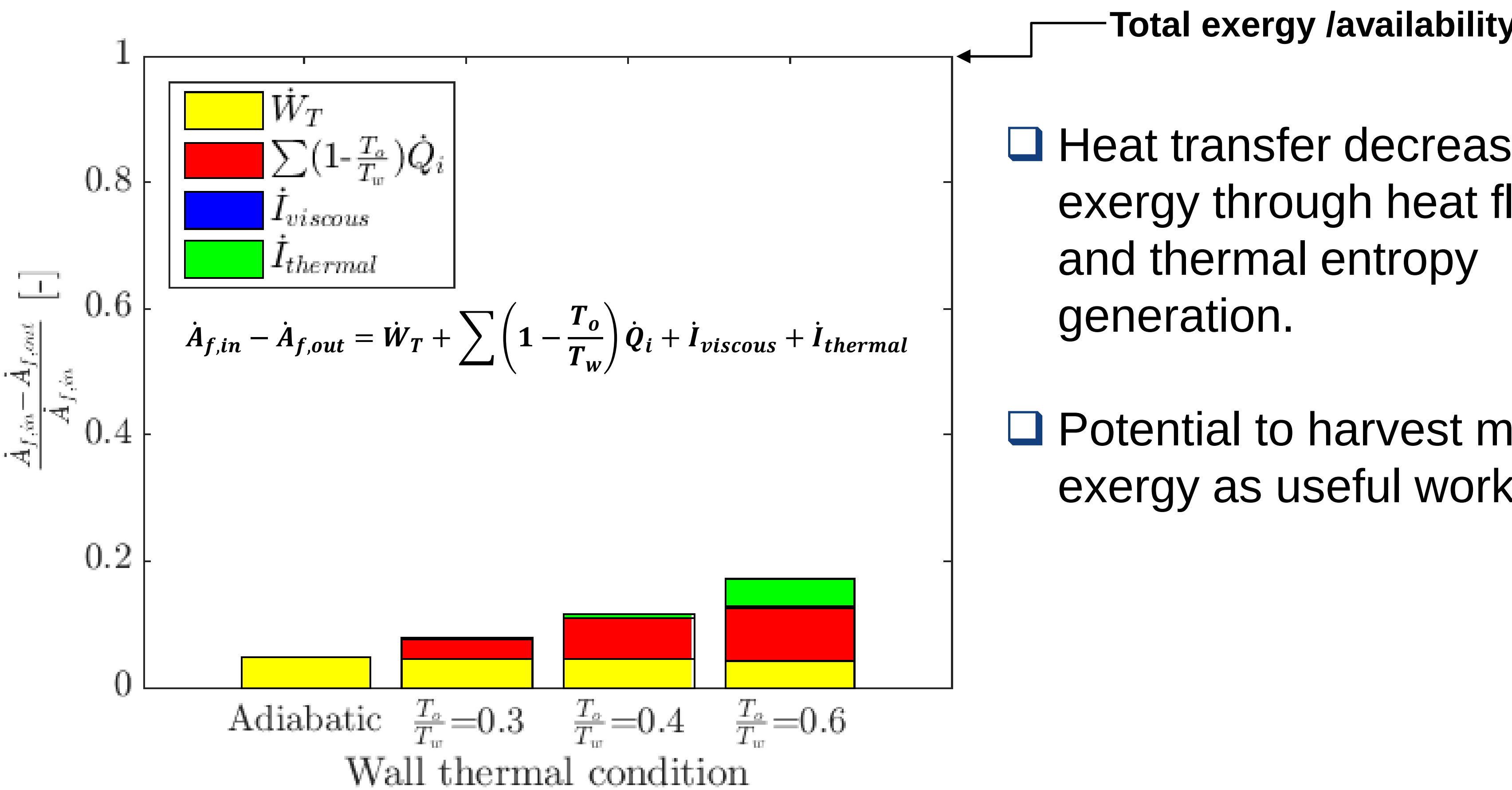

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- Potential to harvest more exergy as useful work.

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Conclusions

- Turbine power is sensitive, but pressure ratio is relatively insensitive to heat loss.
- Possible to quantify heat transfer related losses by using *Exergy* approach.
- Potential to harvest more exergy as useful work in the system (engine-like pulsating flow scenario).

Conclusions

- Turbine power is sensitive, but pressure ratio is relatively insensitive to heat loss.

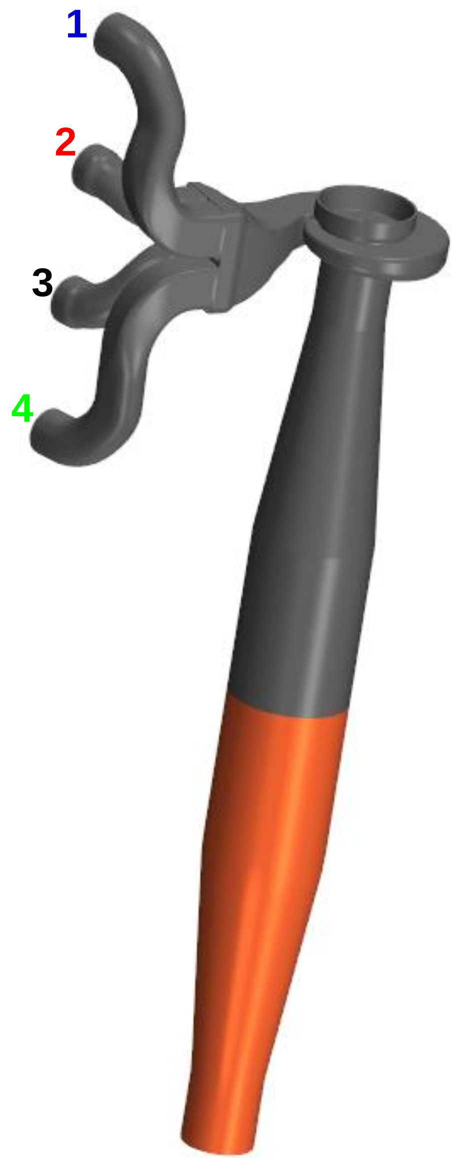
- Possible to quantify heat transfer related losses by using *Exergy* approach.

- Potential to harvest more exergy as useful work in the system (engine-like pulsating flow scenario).

  ⇨ Optimum exhaust valve strategy

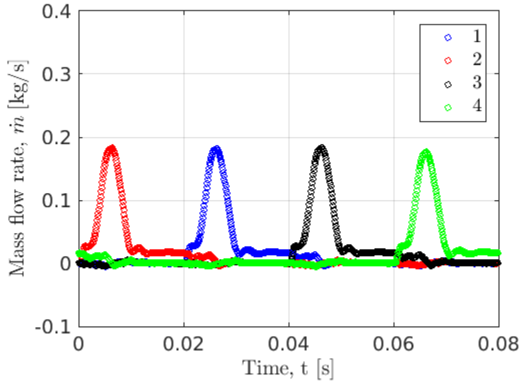
  ⇨ Turbine design

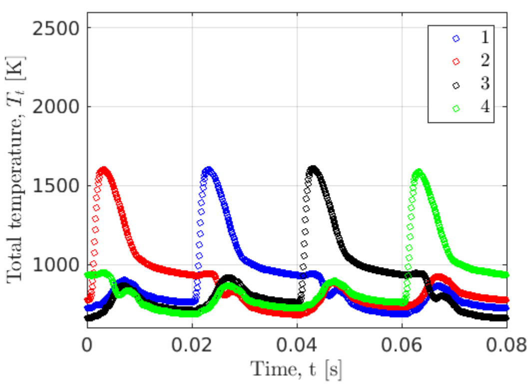
On-going work

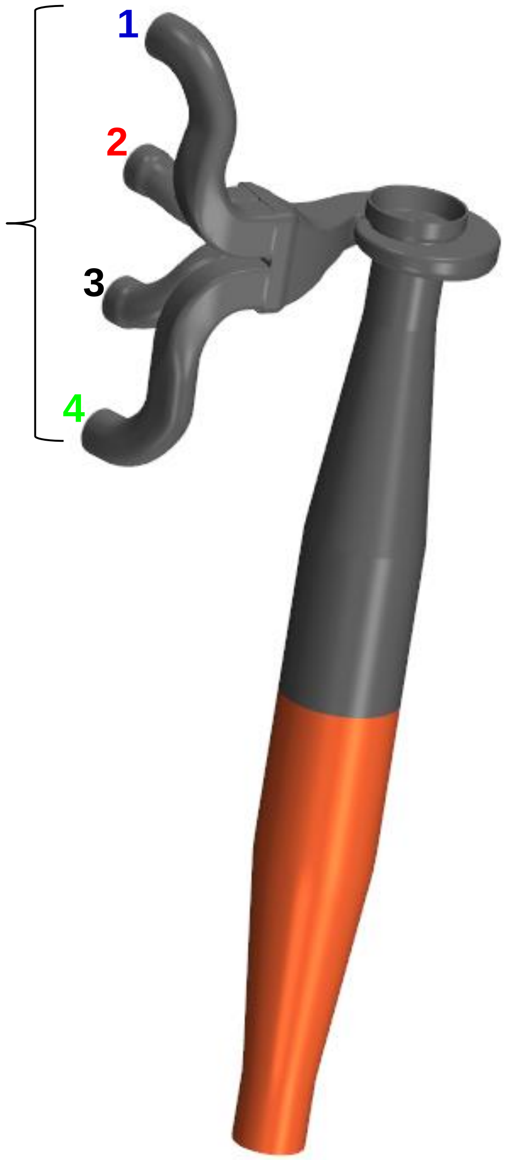


On-going work

Example: n_{engine}=1500 rpm







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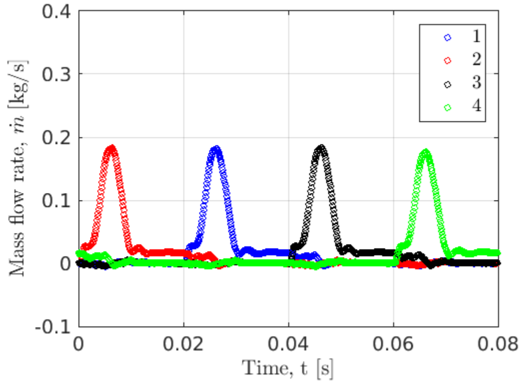

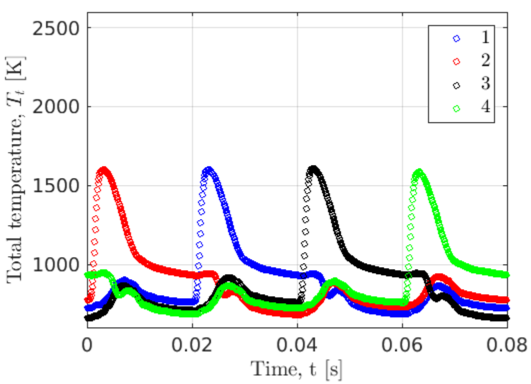

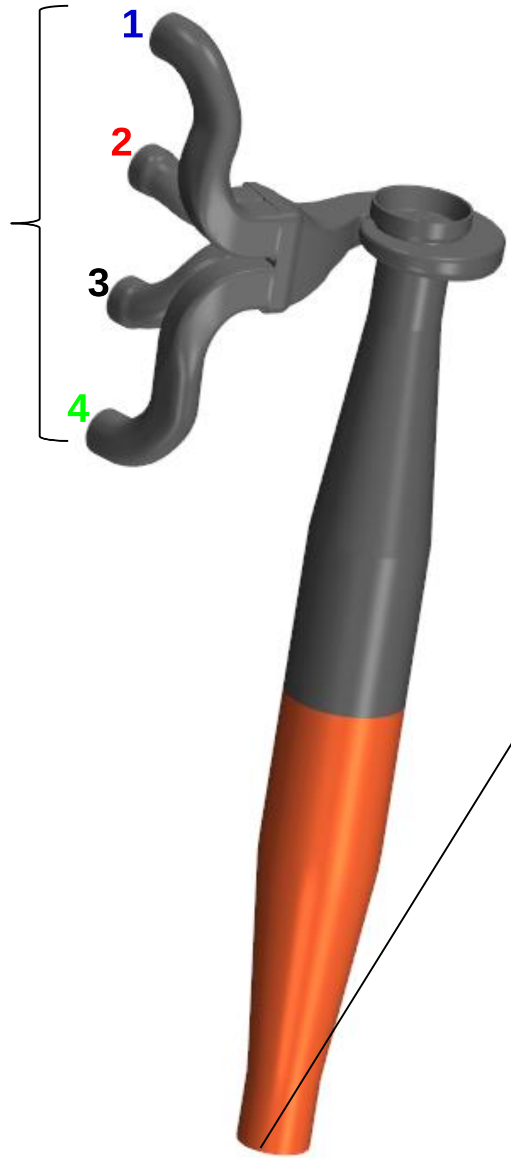

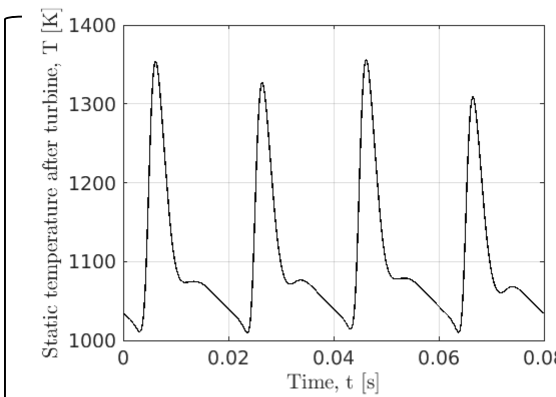

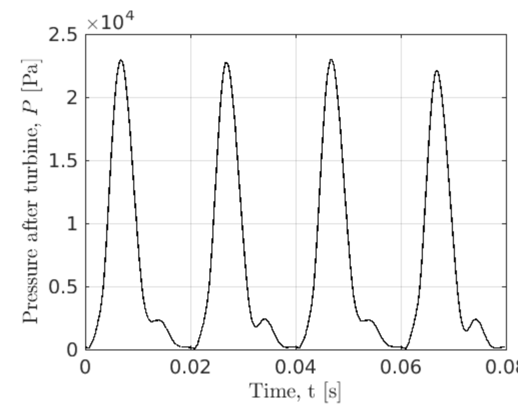

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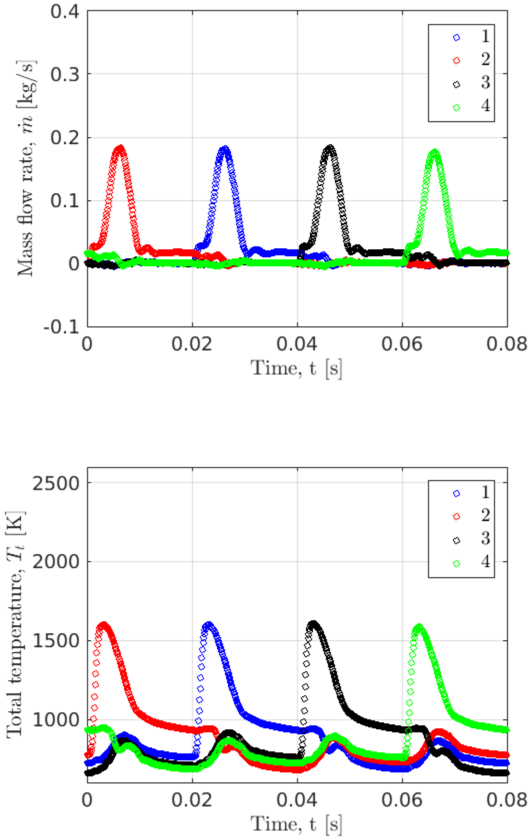
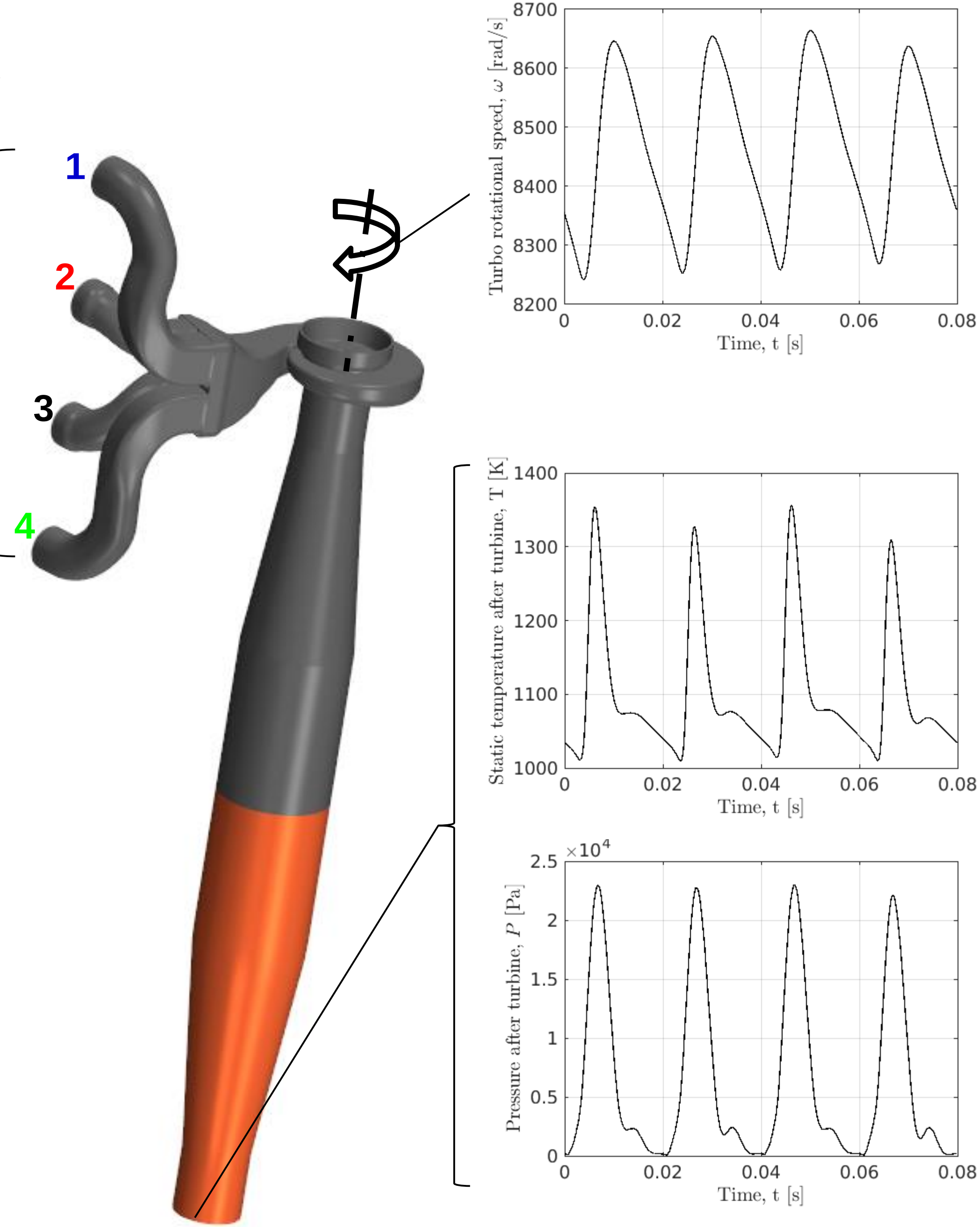


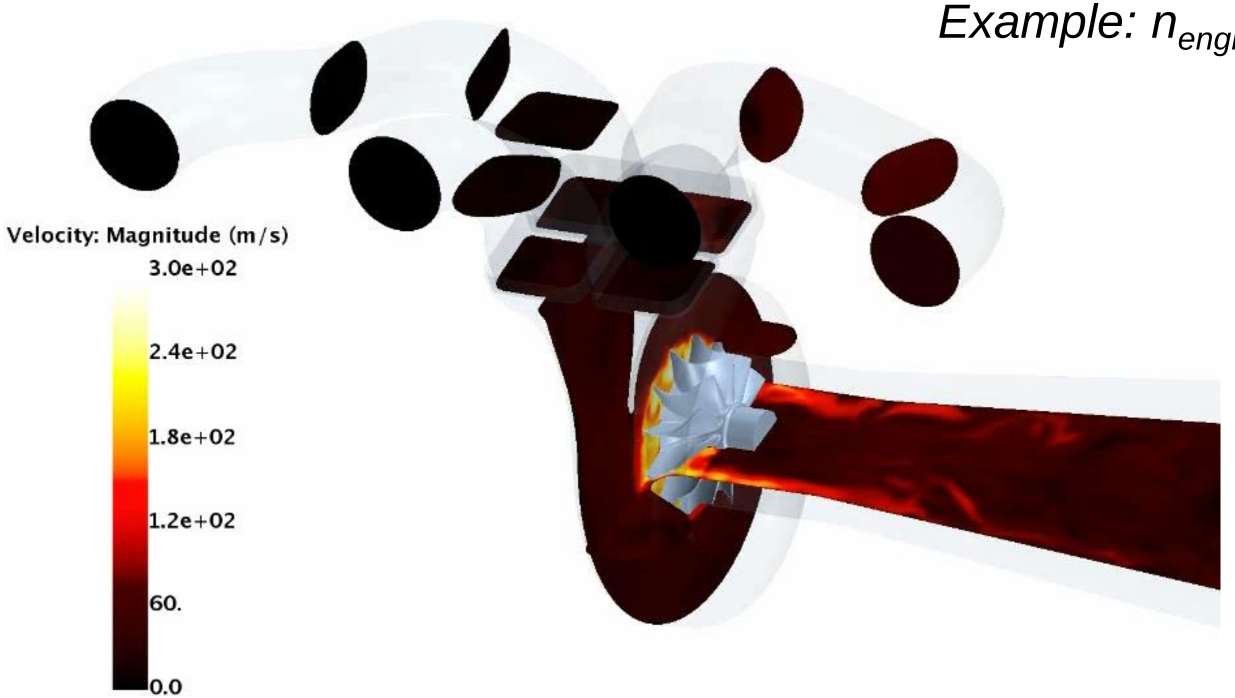


Future work

- Extend exergy analysis on turbine operating under engine-like pulsating conditions to assess upstream exhaust manifolds and flow instabilities on heat transfer and performance.

- Explore different exhaust valve strategy (e.g. pulse shape, frequency, amplitude) for better utilization of exhaust gas flow exergy.

Example: n_{engine}*=1500 rpm*



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