Addressing the Integration Requirements for Thermoelectric Systems in Vehicles

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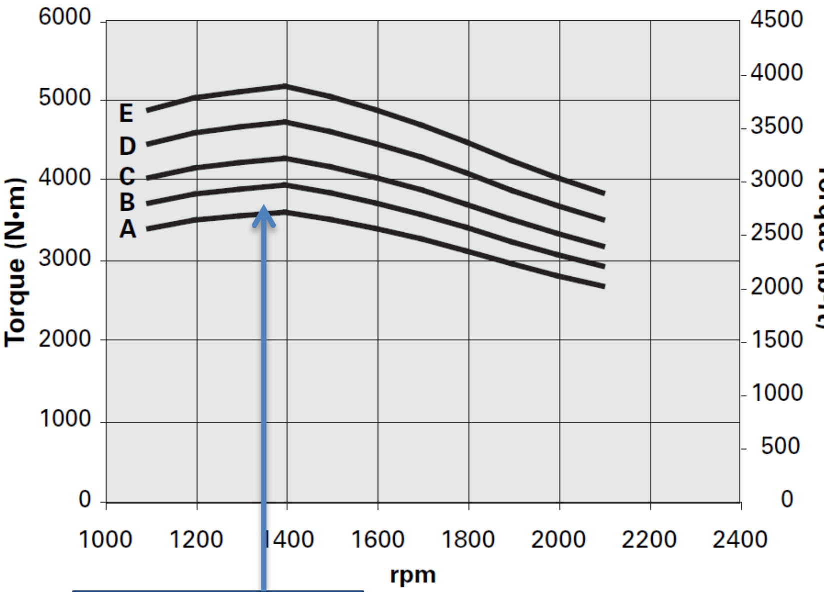
Motivation

- The case for energy recovery in engine powered vehicles
  - Carbon dioxide emissions legislation
  - Fuel economy
  - The increasing degree of electrification in vehicle propulsion
- The challenge
  - Propulsion systems are already well integrated
  - Energy transfers already calculated
  - After-treatment conditions critical and finely tuned
- The opportunity
  - Our understanding of energy management
  - Optimal conditions and the on-line/off-line split of design effort

Agenda

- The potential for energy recovery in vehicles
- Energy recovery methods – a comparison
- The integration process – defining the requirement
- The progression of modelling – supporting the integration process
- Analysis leads to design guidelines – and choice of heat exchange architecture
- Optimisation – off-line and on-line

Caterpillar D10T2



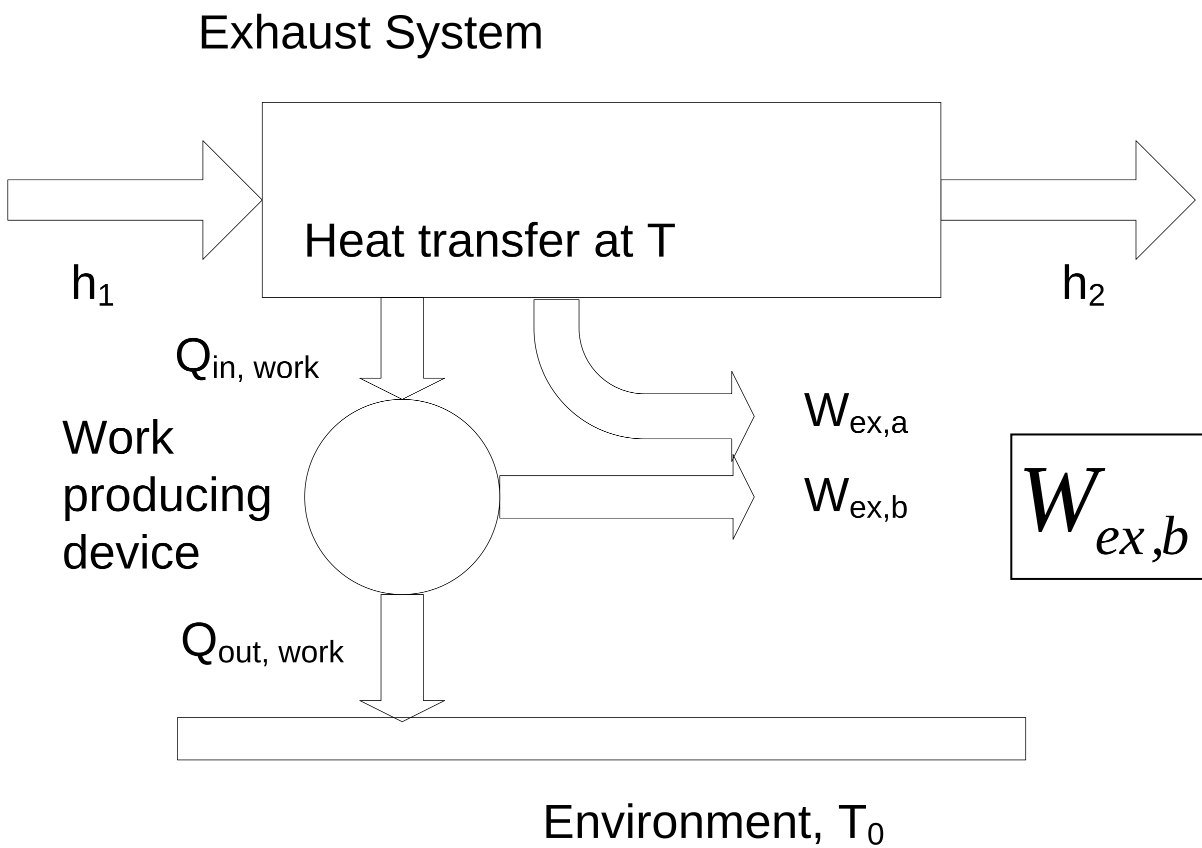
P = 513 kW

$\dot{H}_e$ = 600kW

Energy recoverable

Exhaust gas = 210 kW
Coolant = 12kW

The Energy Available

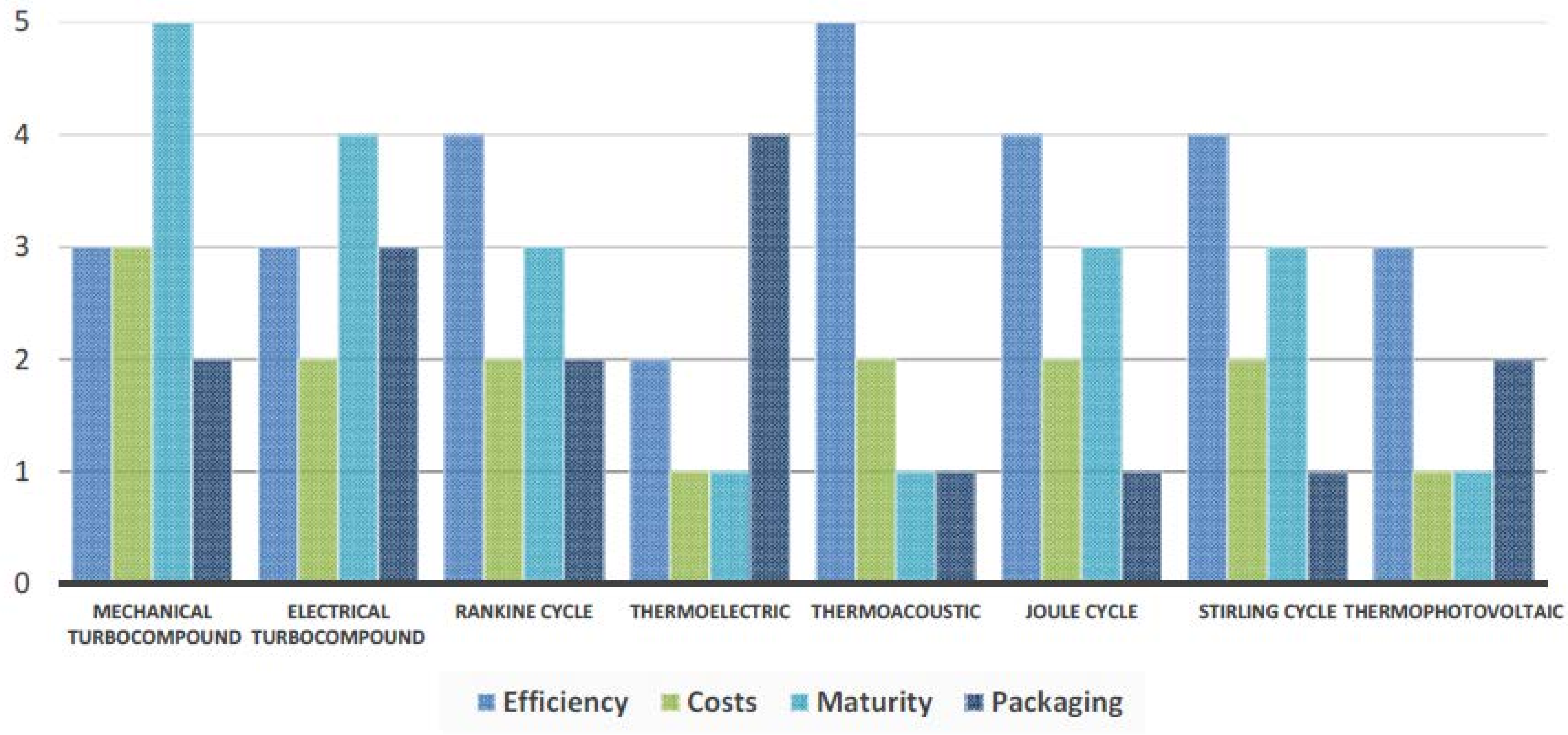


$$W_{ex,b} = b_1 - b_2$$

Methods of Energy Recovery

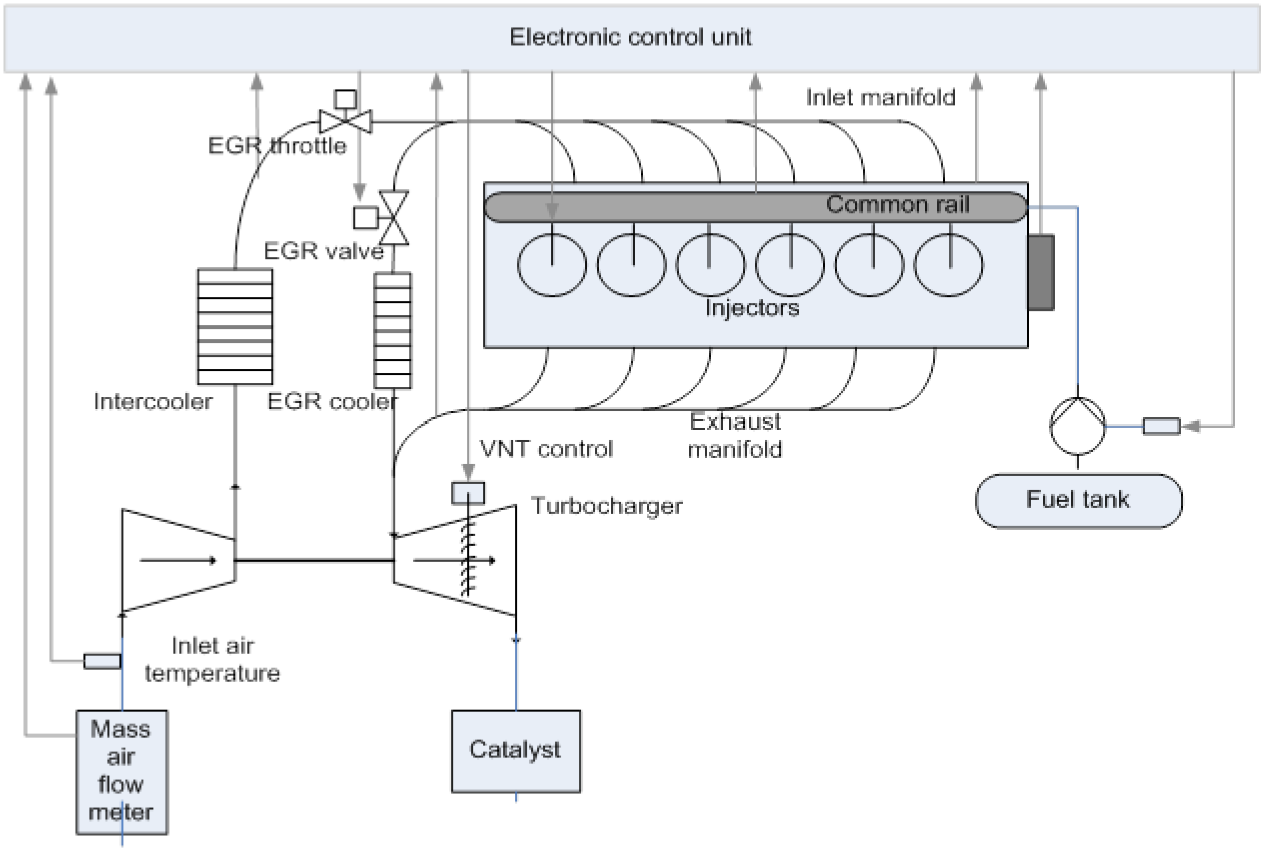
- Mechanical or electrical turbo-compound
  - Additional expansion energy
- Rankine Cycle
  - Separate vapour power cycle
- Thermoelectric
- Themoacoustic
- Joule (or Brayton) cycle
  - A closed form of the gas turbine cycle
- Stirling Cycle
- Thermophotovoltaic

A comparison



Energies **2014**, *7*, 5273-5290; doi:10.3390/en7085273
Arnaud Legros *et al*, Comparison and Impact ….

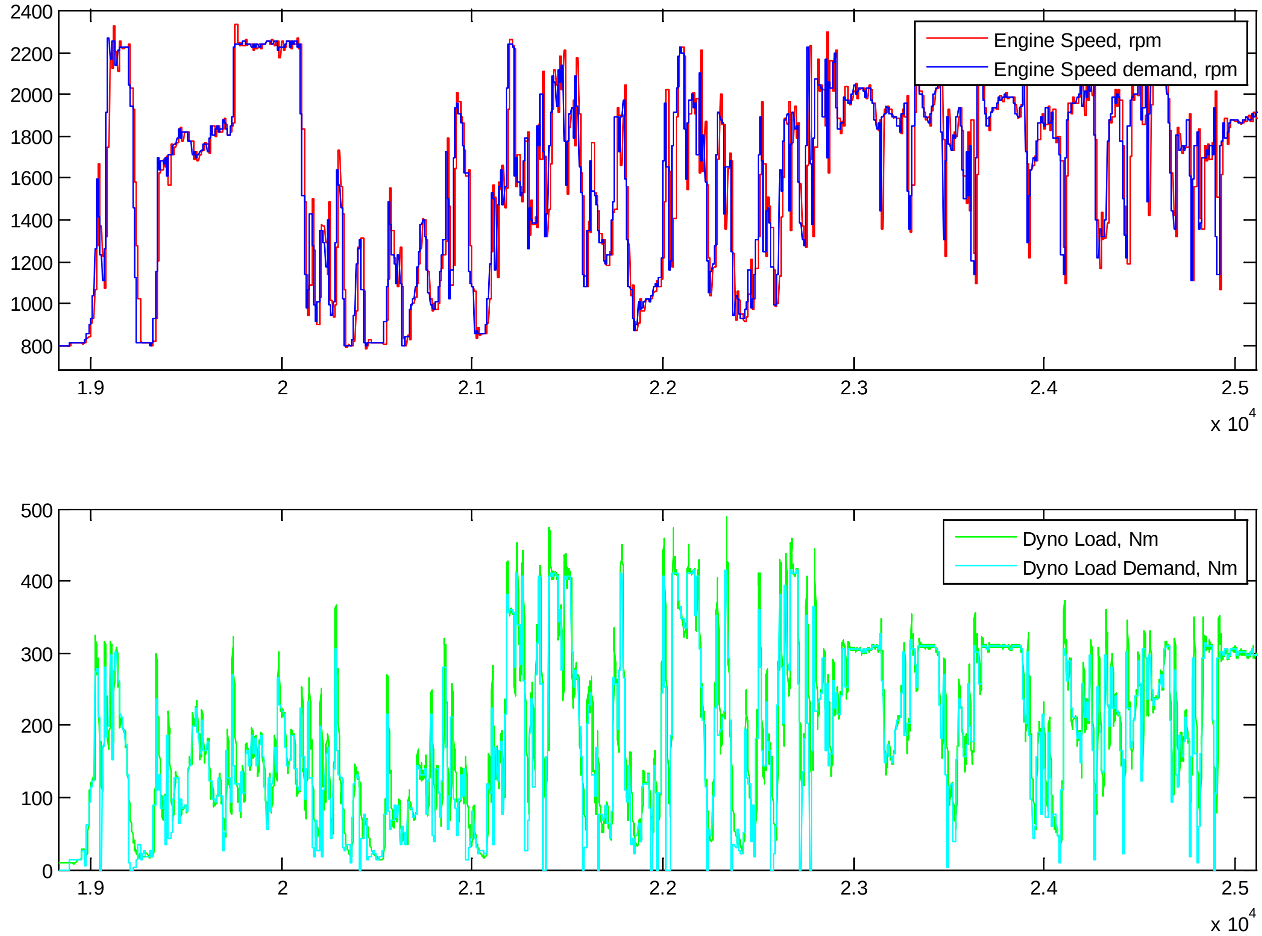
A diesel engine



The Integration Process?

- The application
  - Sources of energy - Temperature, gas flow rate
  - Constraints - Temperature change, pressure drop
  - Duty cycle
- The requirement – power, current, when?
- Choice of heat exchange architectures
- Stages of modelling
  - Screening – Design – Analysis
  - Manufacturing considerations
- Control methods

A Duty Cycle – the Non-Road Transient Cycle (NRTC)



NRTC
The first 600 sec

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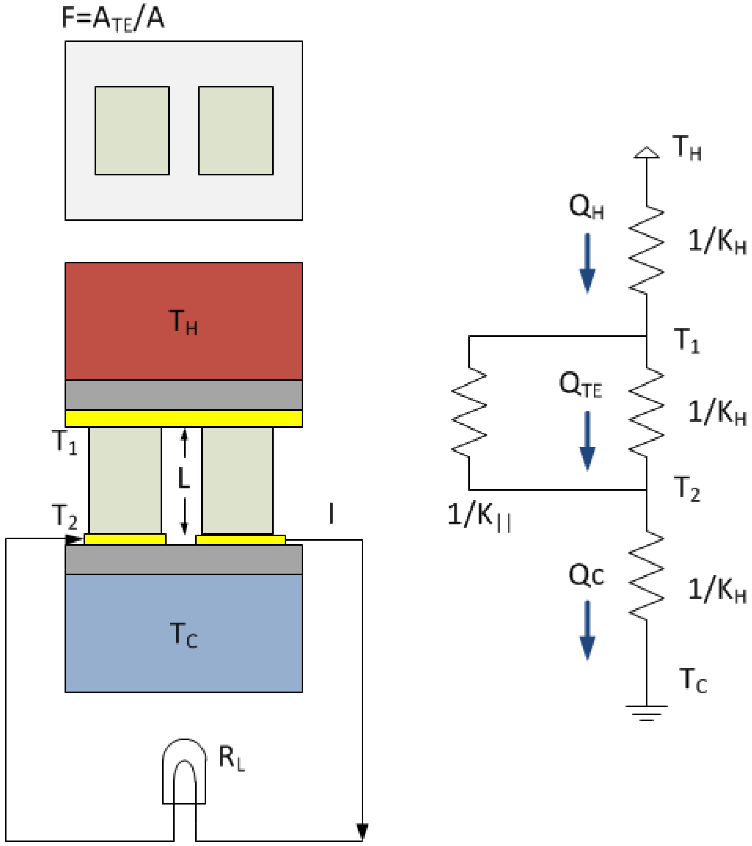
The modelling progression (1)

- Closed form solutions
- "$ per W metrics …", Shannon Yee at al.
- Motivation to provide to compact solutions to support a cost evaluation

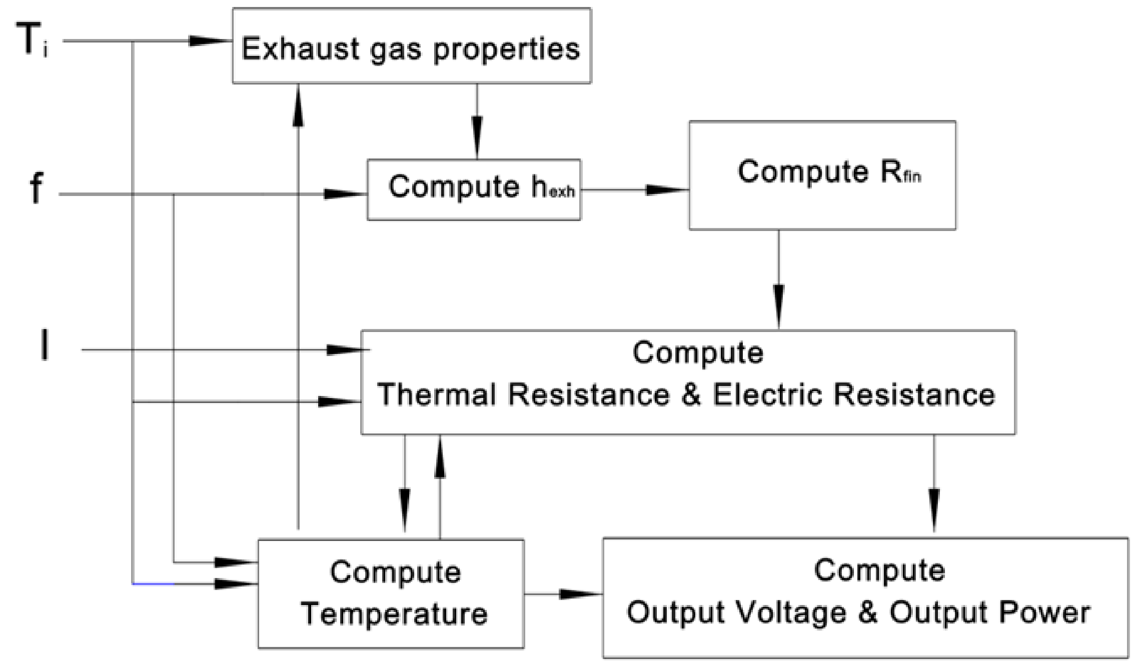
$$P = \frac{S_{np}^2 \sigma (T_1 - T_2)^2 AF}{4} \left(\frac{m}{(m+1)^2}\right)\left(\frac{L}{(2L_T F + L)^2}\right)$$

$$T_1 - T_2 = \frac{1}{2}(T_H - T_C)$$



The modelling progression (2)

- Based on physical parameters and empirical correlations
- Requires a set of governing equations for modules, heat exchange and electrical power
- Typically 50-100 equations



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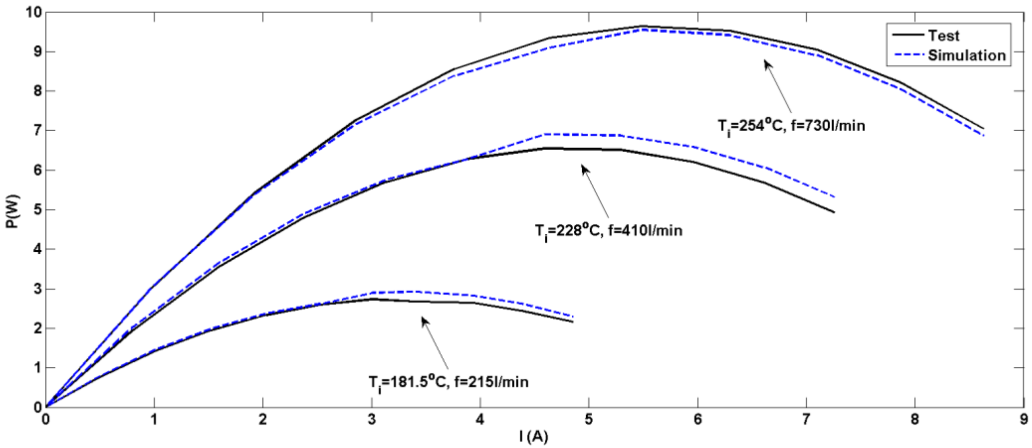
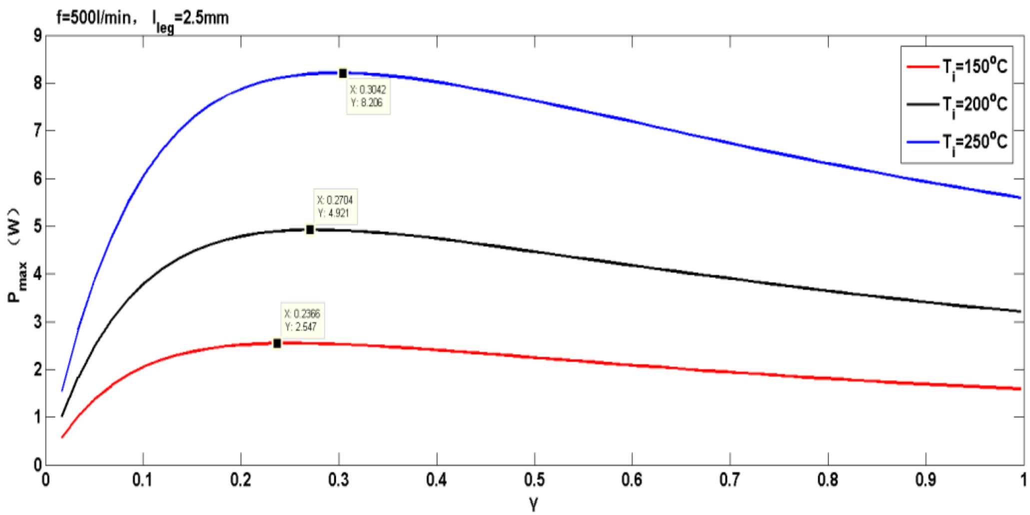
The modelling progression (2)

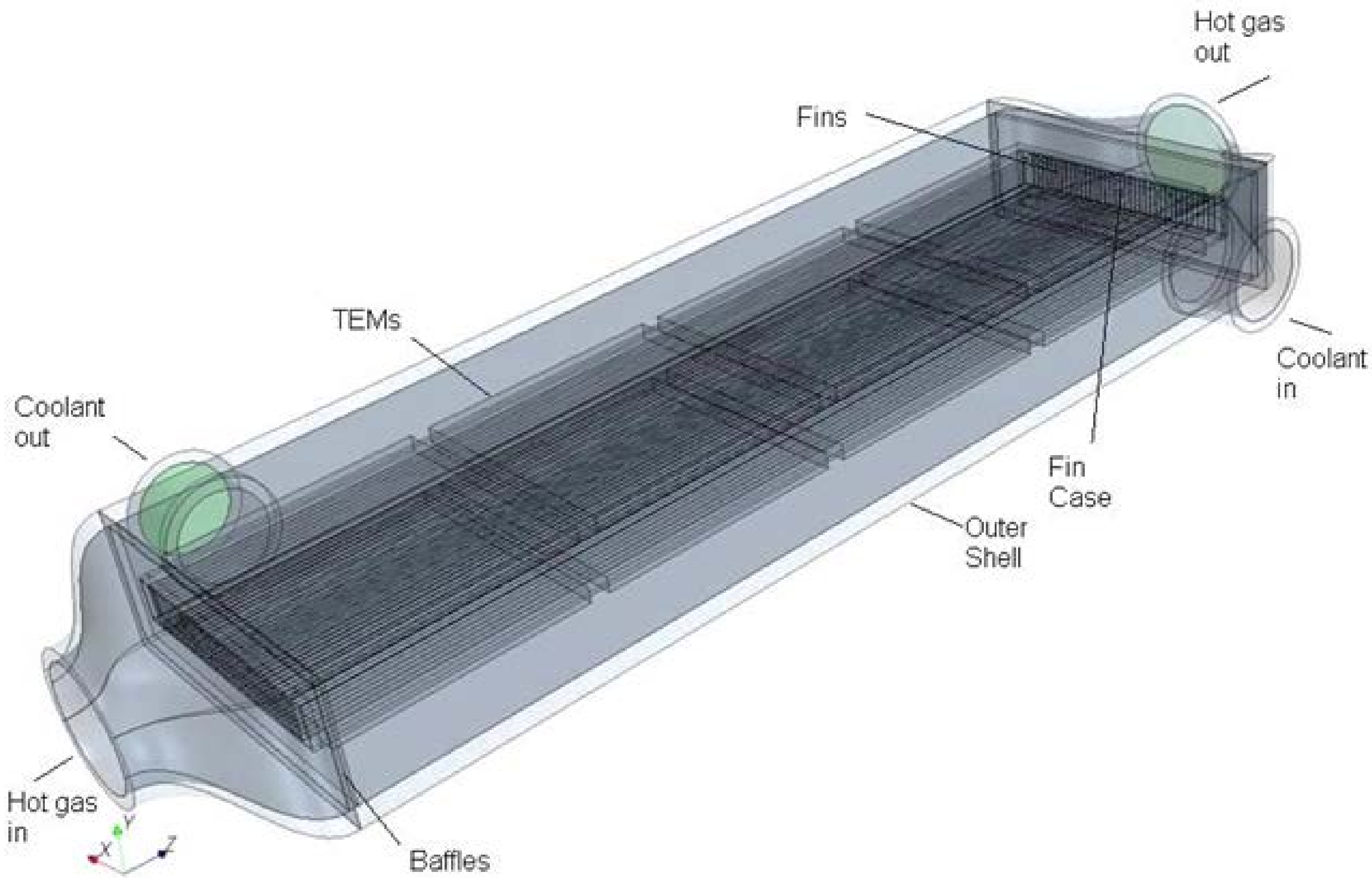


Validation at three different exhaust flow conditions.

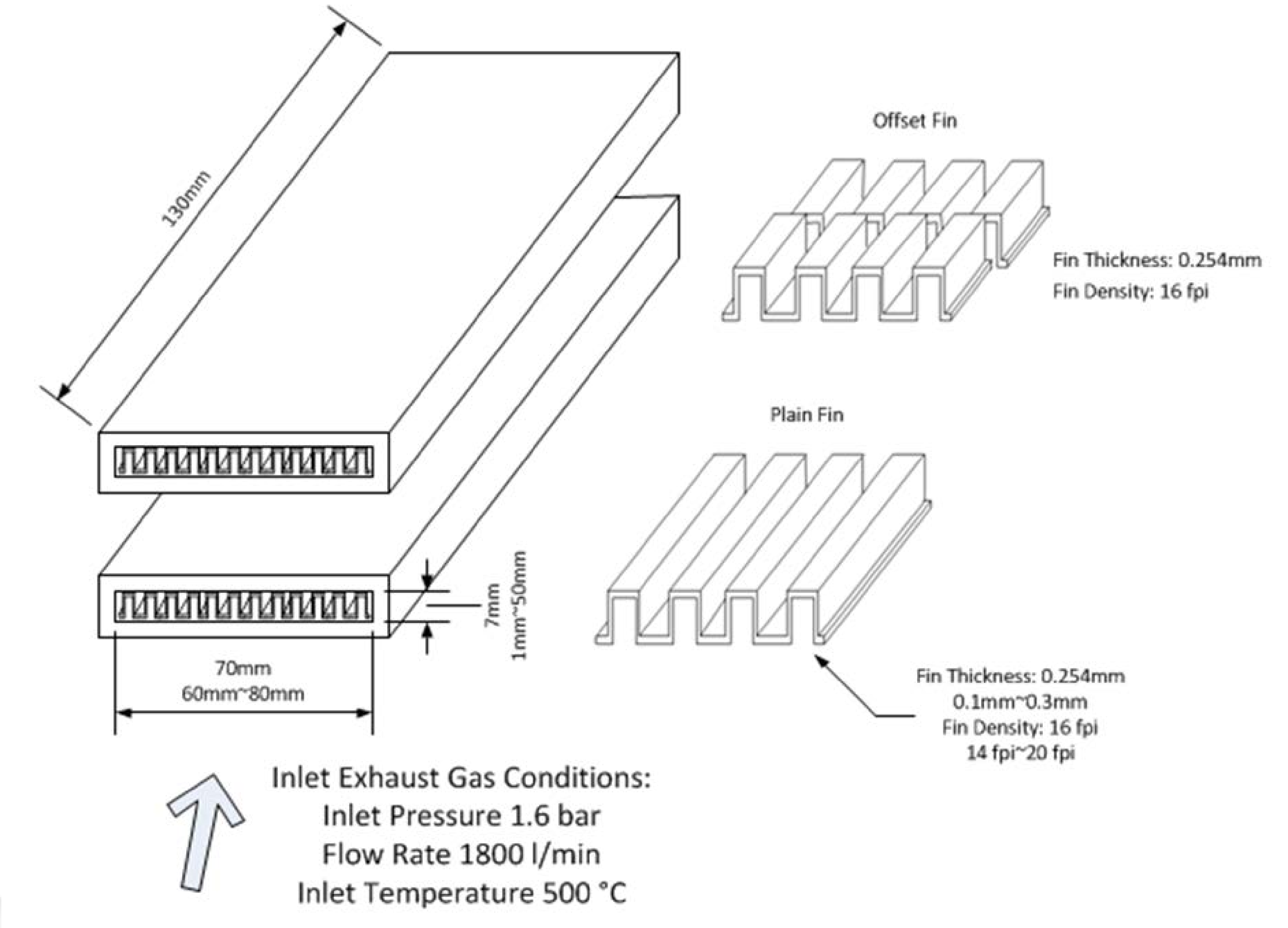


Variation of power with fill ratio at different exhaust temperatures

The modelling progression (3)



Heat exchanger construction



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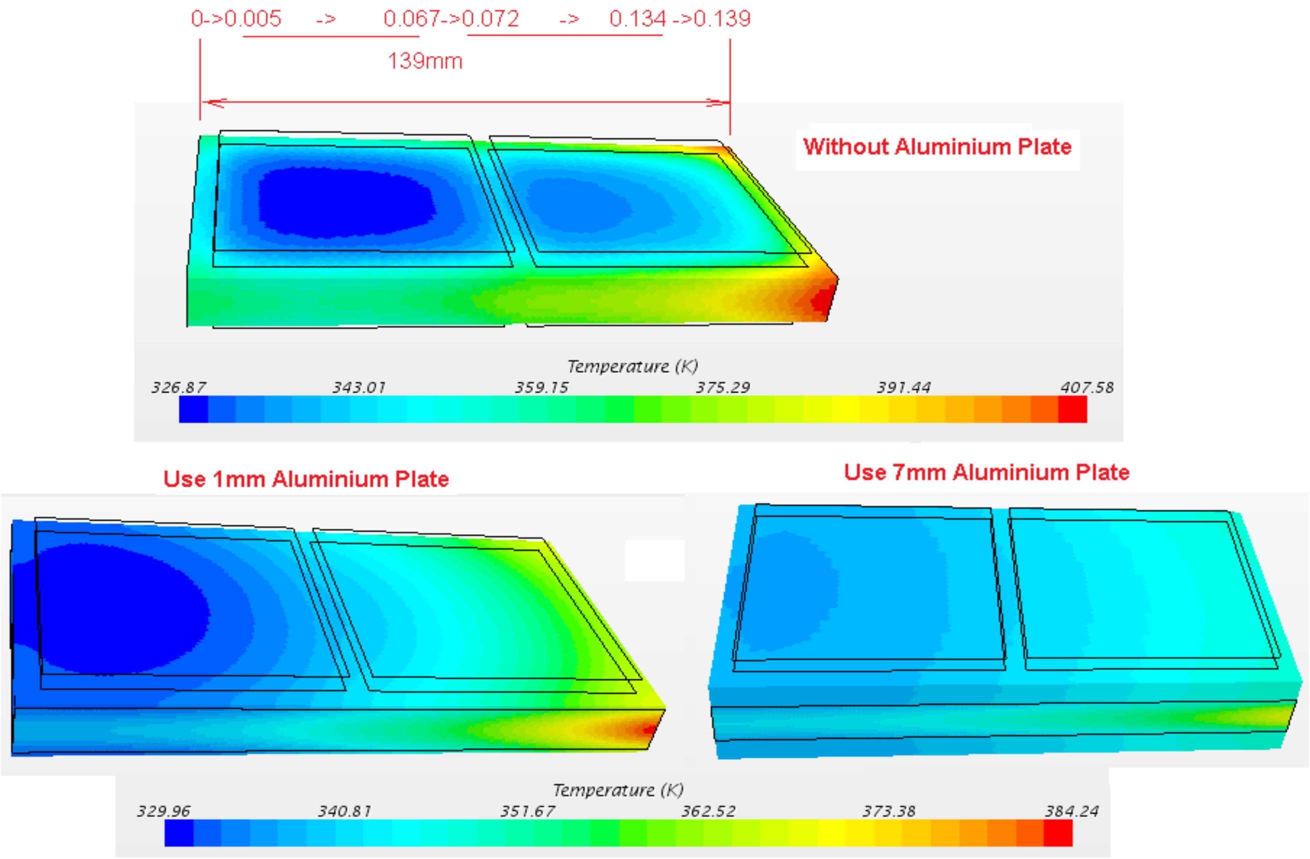
Investigating spreading resistance



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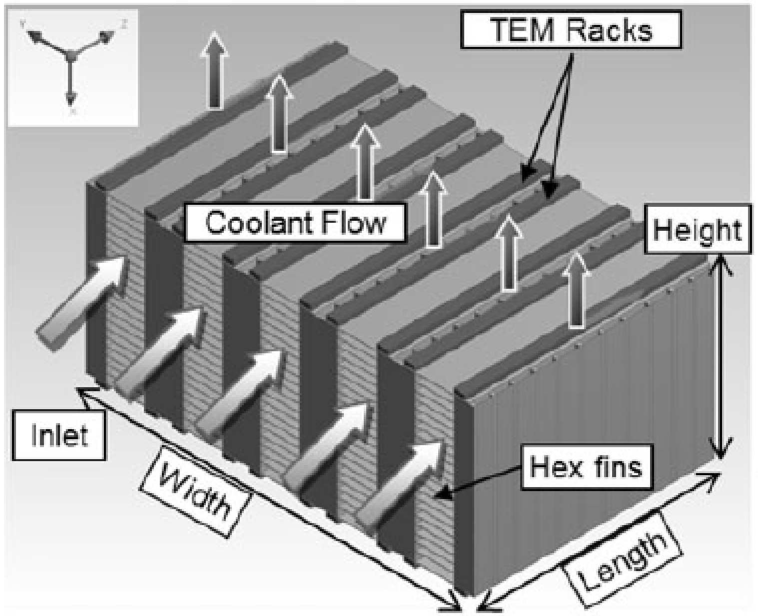
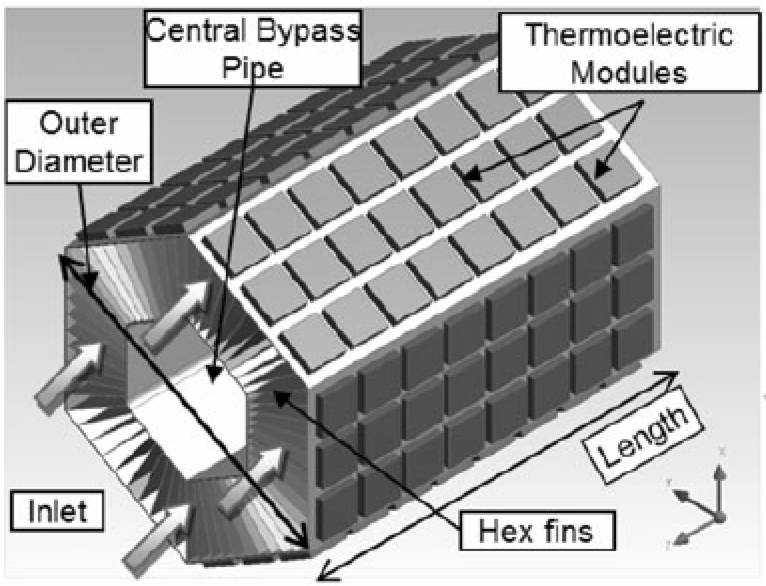
Creating a design guide – an example

1. Use plain fins.
2. The selection of channel width should consider the TEM dimensions.
3. Channel height should not be less than 10mm.
4. Fin thickness can be set at about 0.2 mm.
5. Use high fin density under the constraints of pressure drop and heat exchanger weight.
6. The choice of fin density will also rely on the manufacturing processes available.

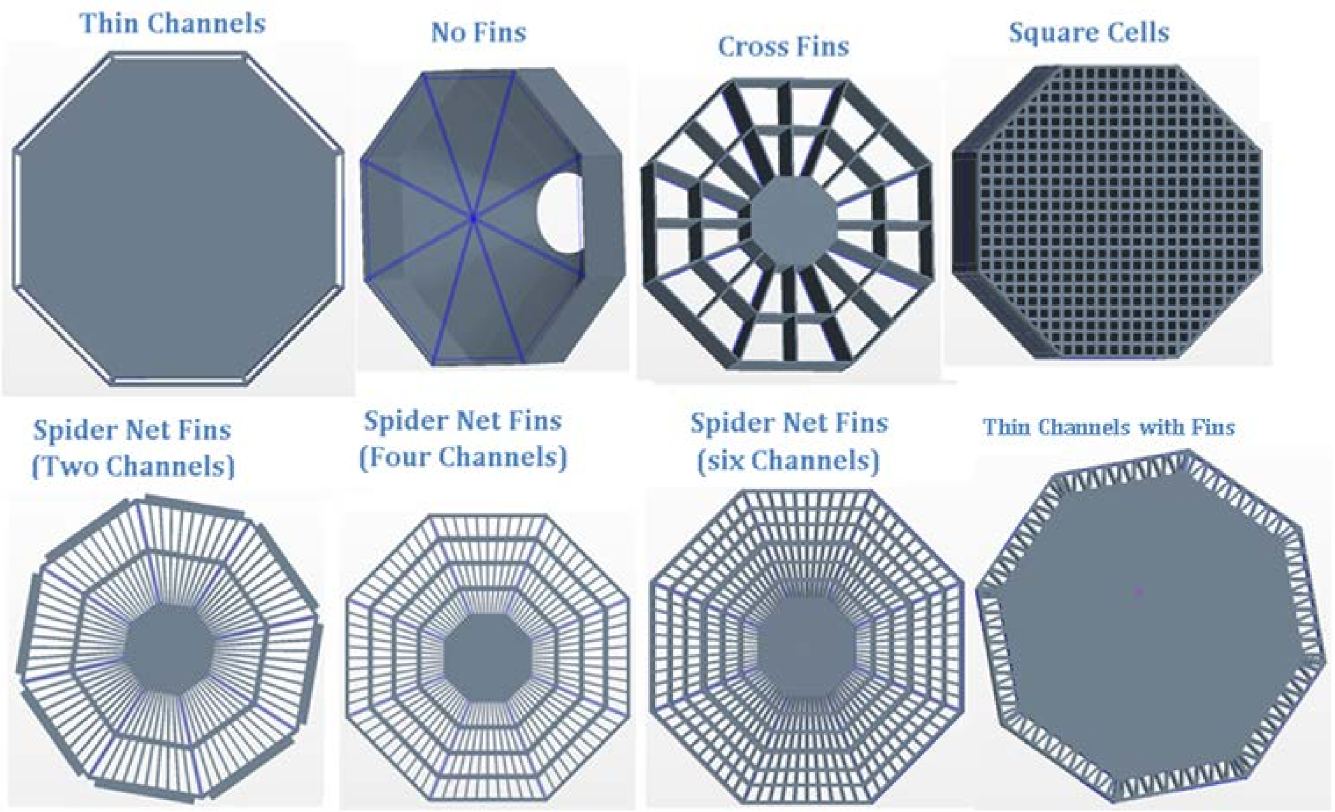
The choice of heat exchange architecture



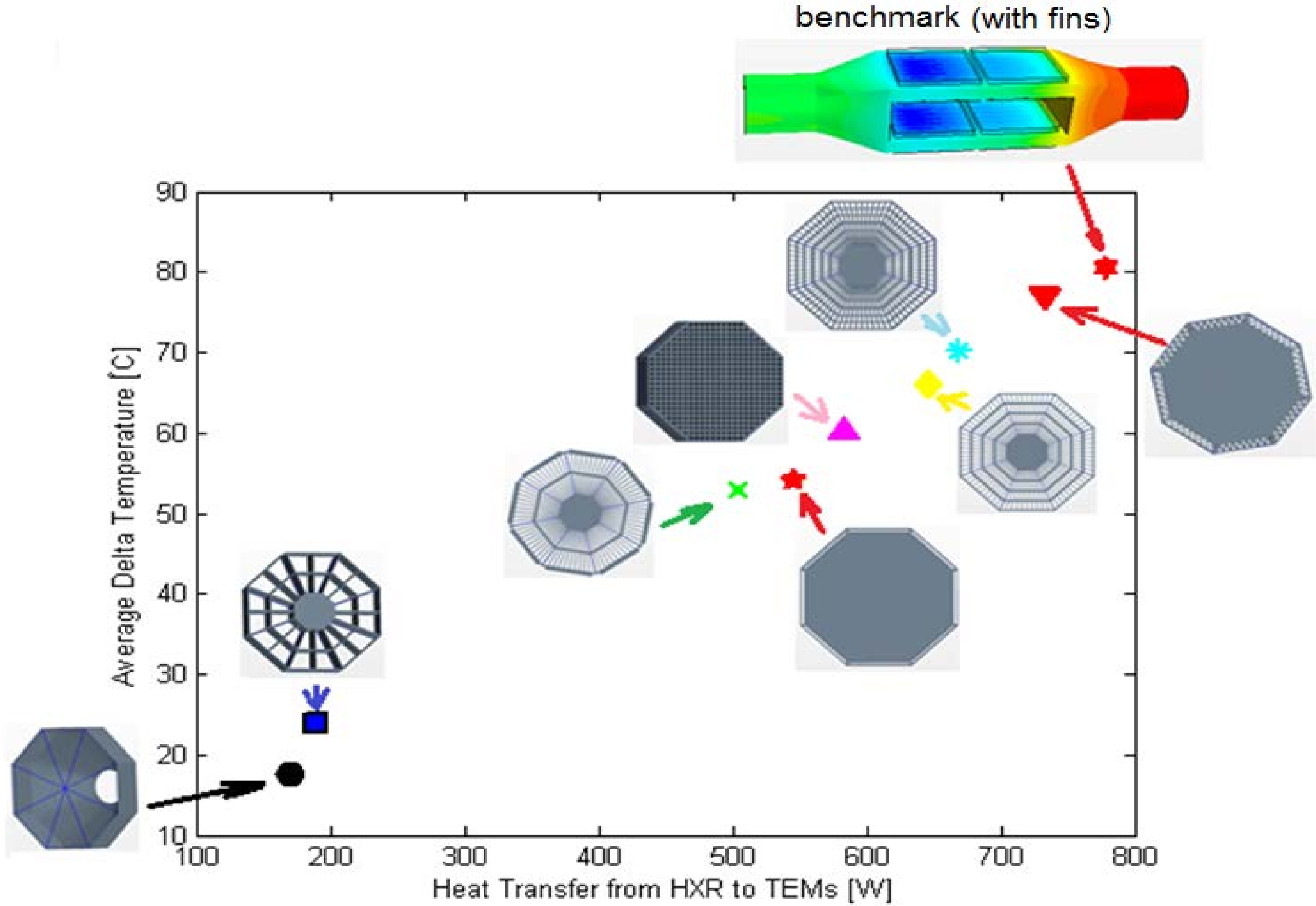


Sumeet Kumar, Stephen D. Heister, Xianfan Xu,, James R. Salvador, And Gregory P. Meisner, Thermoelectric Generators …., Journal of ELECTRONIC MATERIALS, 2013

Octagonal design



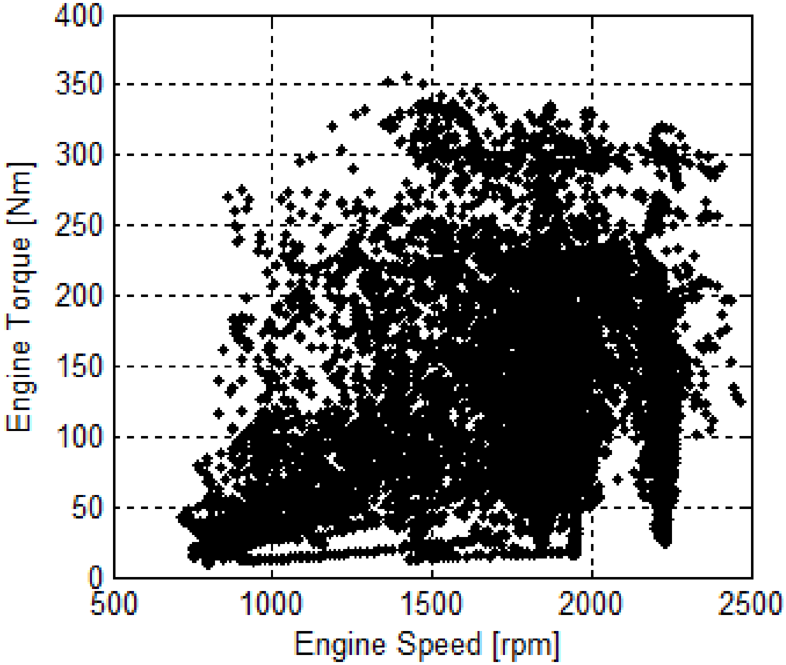
Performance comparison



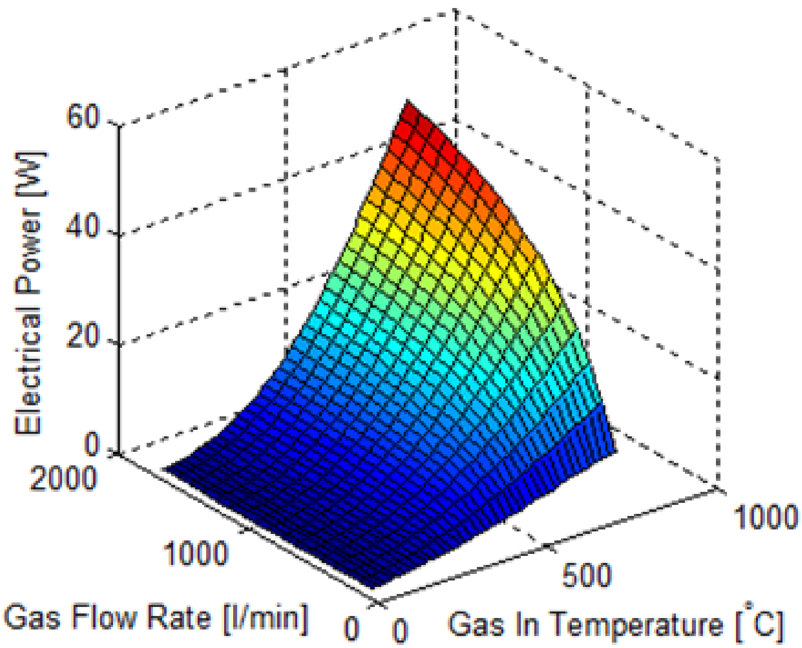
An optimisation exercise

The test engine

Distribution of torque points

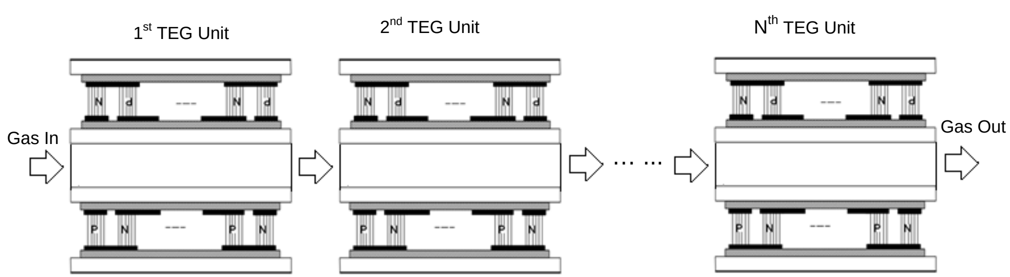


Using a TEG model



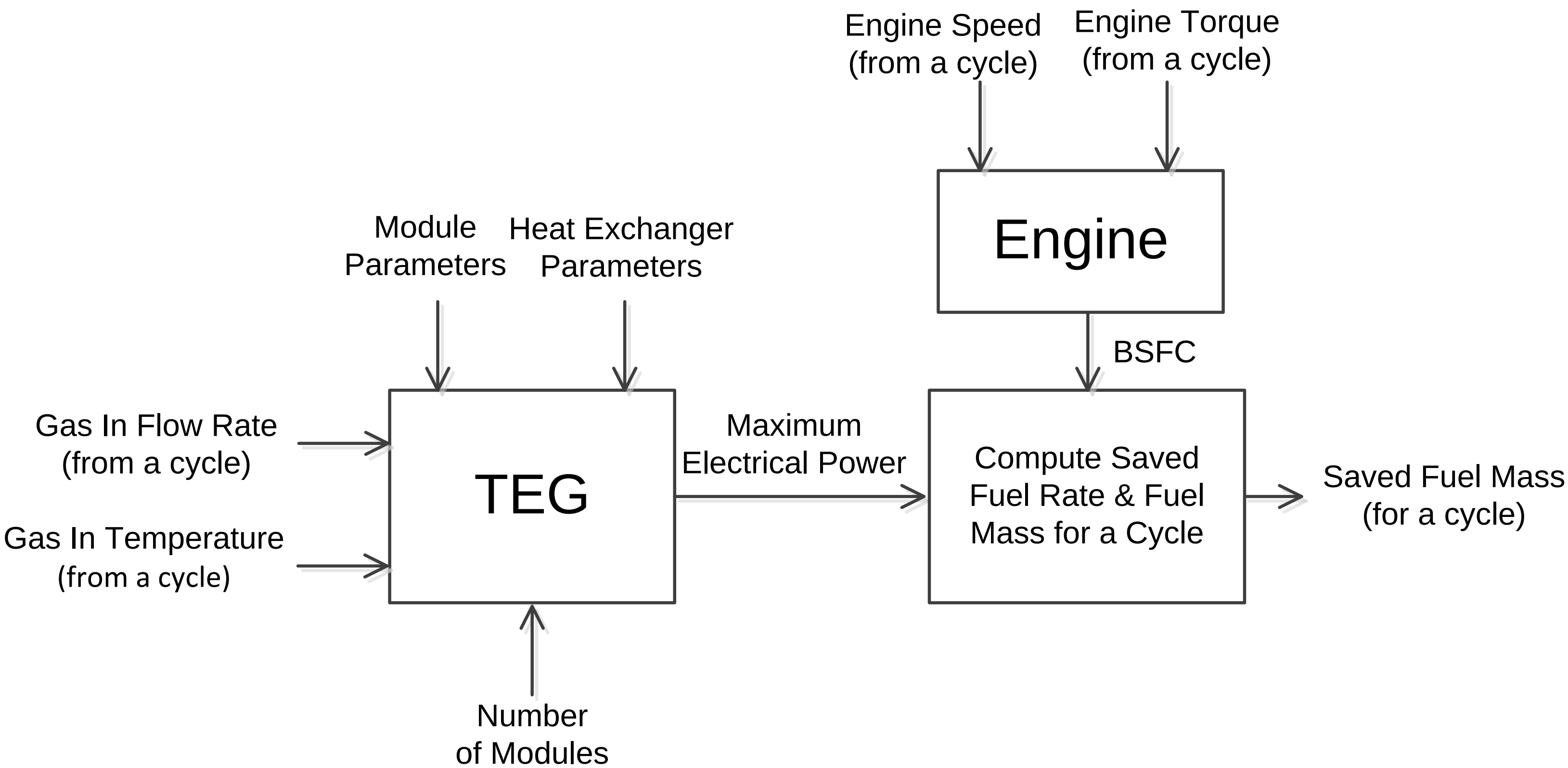
The validated model

The model forms part of the optimisation "loop"



The TEG pattern

The Optimisation Process



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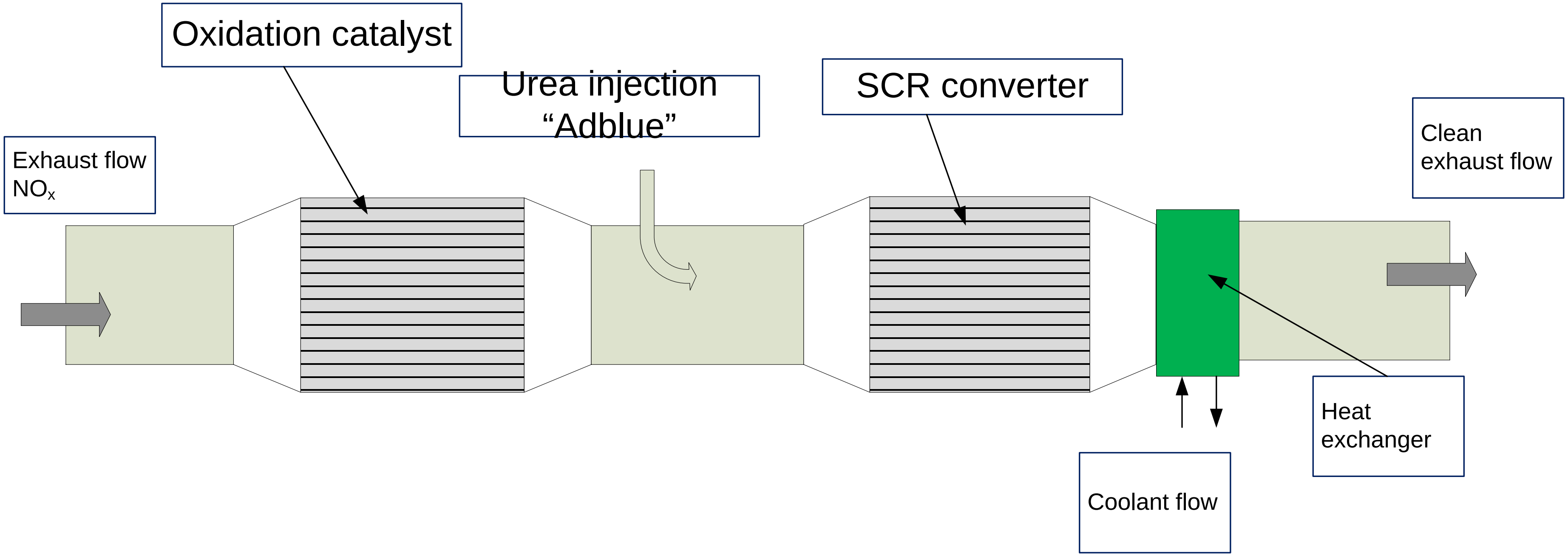
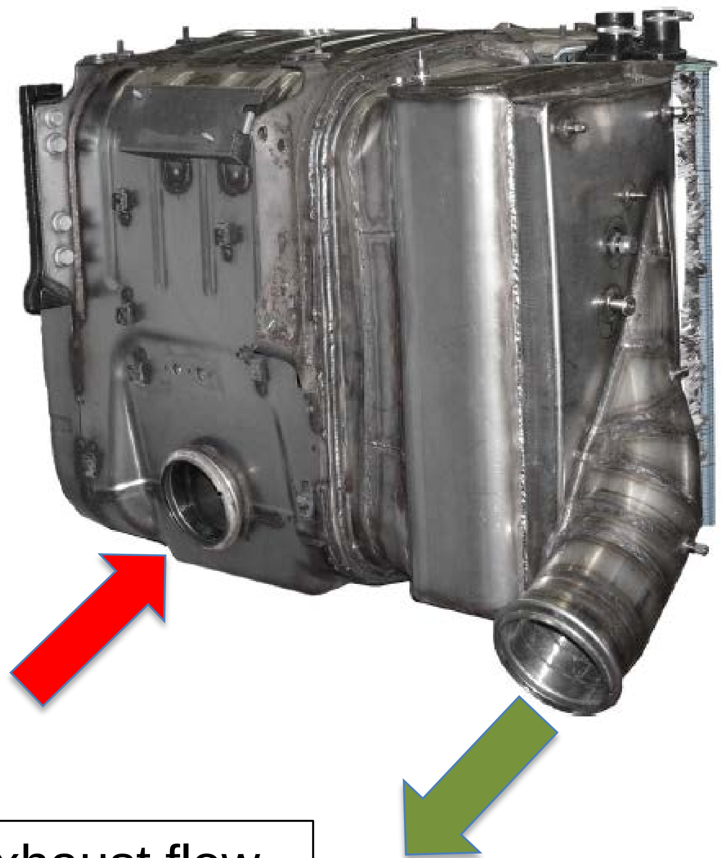
The Exhaust System

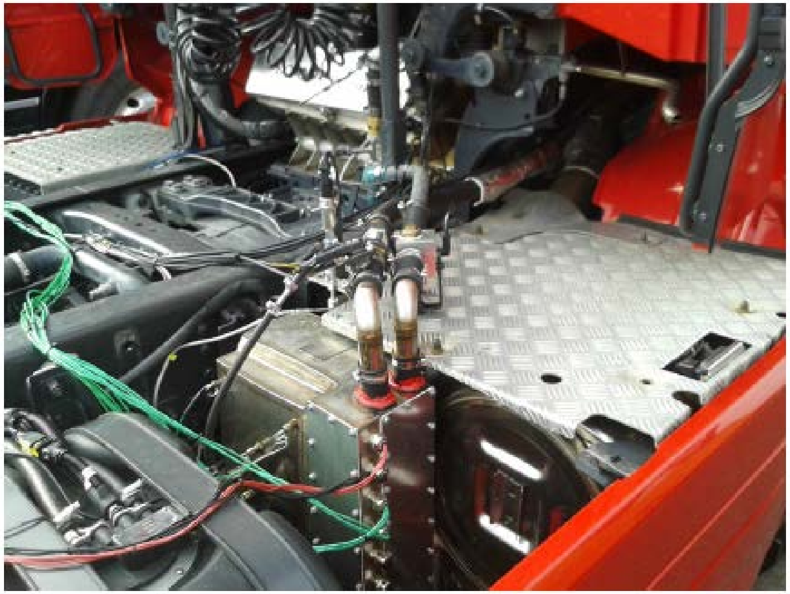


Fabian Frobenius, Gerd Gaiser, Ulrich Rusche, Bernd Weller, *Thermoelectric Generators for the Integration* …, Journal of Electronic Materials, September 2015

Integration on a heavy duty truck



Exhaust flow



Observations

- The integration process is not unique to TEG – and adopts the character of “host” product development process
- Requirements fundamental – includes constraints
- Modelling is fundamental to the integration process
- Deployment of optimisation for both design and operation can be supported by a family of models
- The key challenges are *characterisation* and *modelling*