Challenges in Modeling Complex EV Thermal Management Systems

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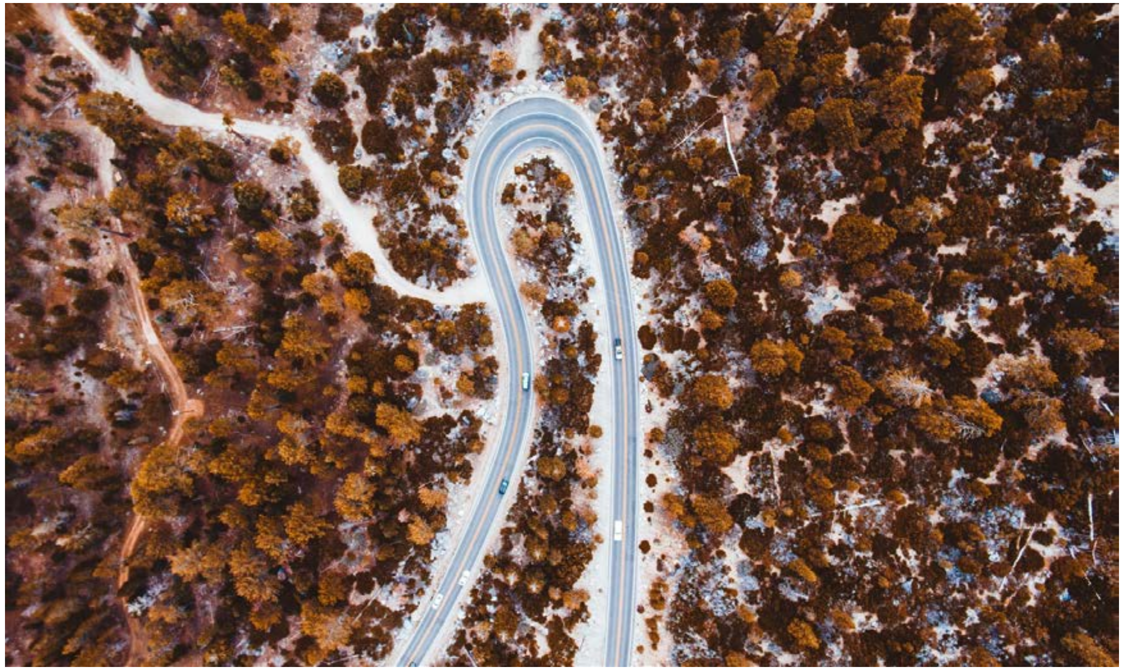
Component Modeling

General Best Practices

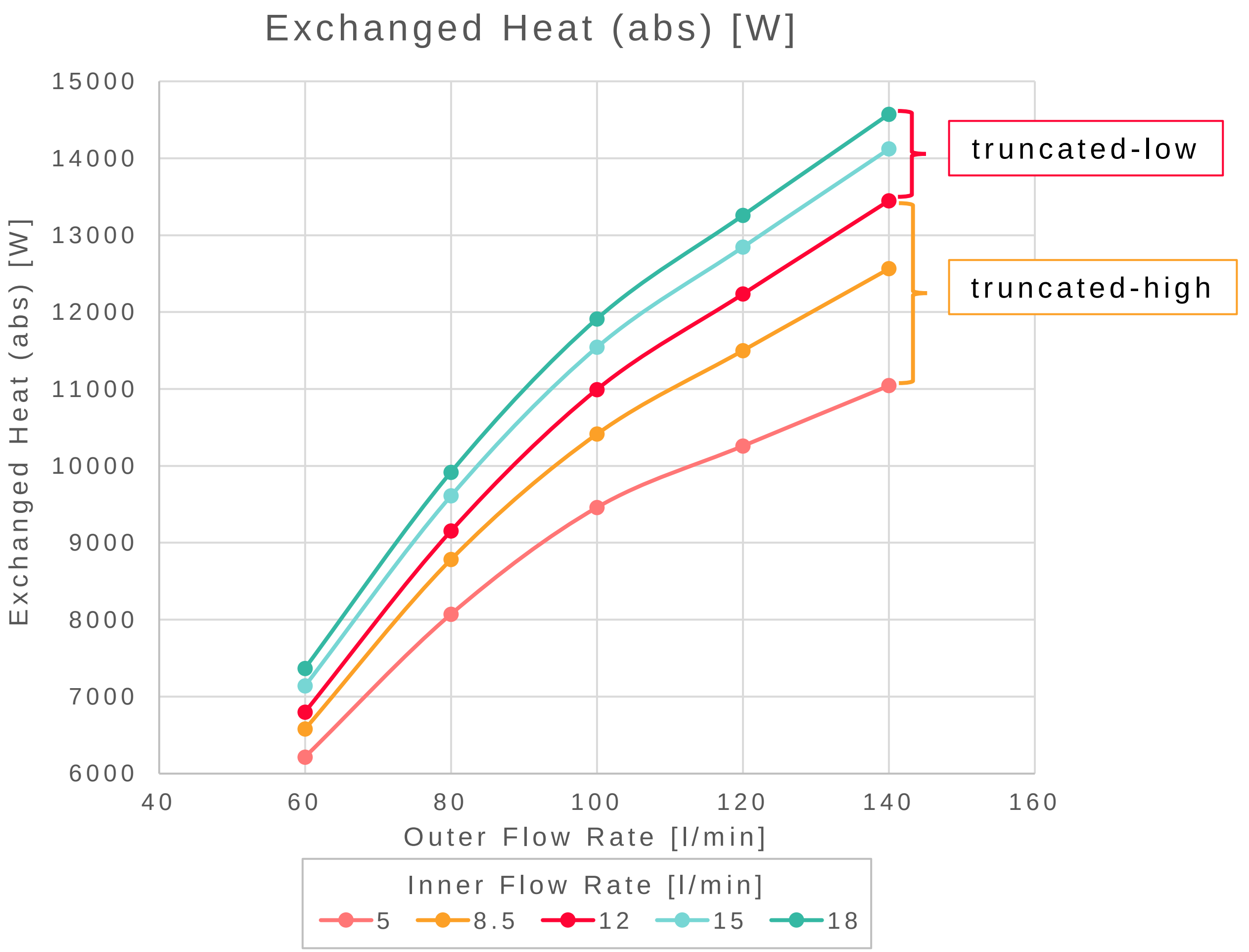
HOW TO HANDLE COMPONENT DATA

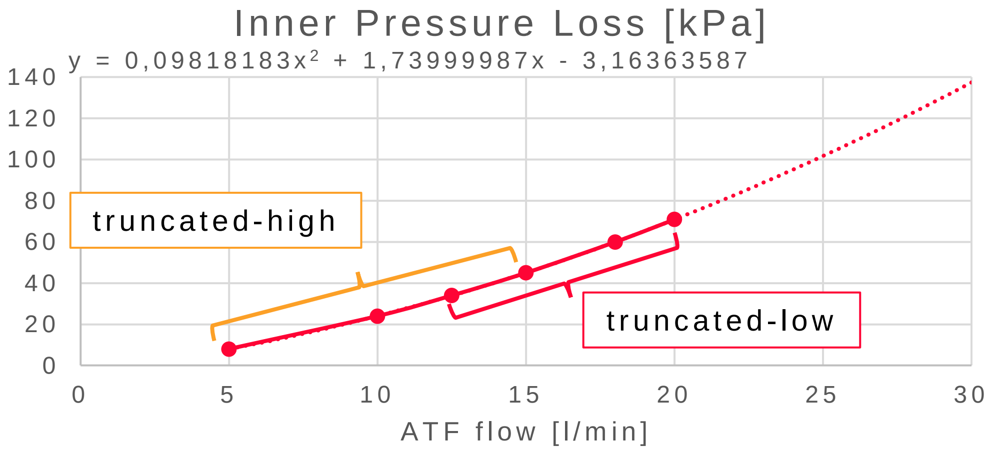
- Extrapolating more that 5-10% is not advised.
- Interpolating is usually not a problem -- cover your desired range and you'll be fine.
- When the operating range is large, you may calibrate for high volume and low volume flow ranges separately
  - This approach results in 2 component files…
  - …but results are better and solve faster!
- It is important to always do some inspection of all component data before we use it in a model. Bad data will cause bad results at best, or no results at worst.
- <u>*Always*</u> check the data!

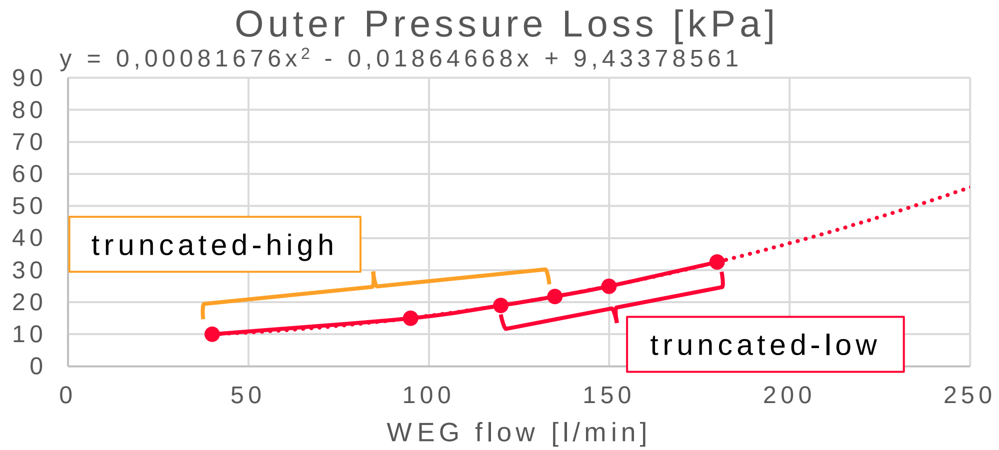


Effects of Extrapolation - Inputs

A PLATE HEAT EXCHANGER, A COMMON COMPONENT IN EV THERMAL SYSTEMS



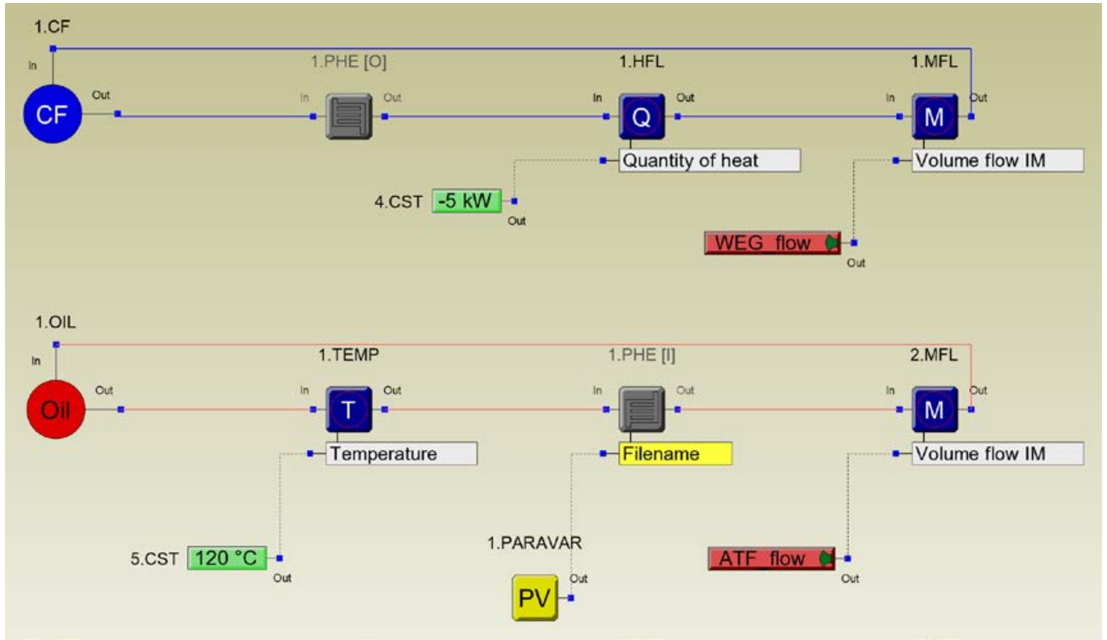


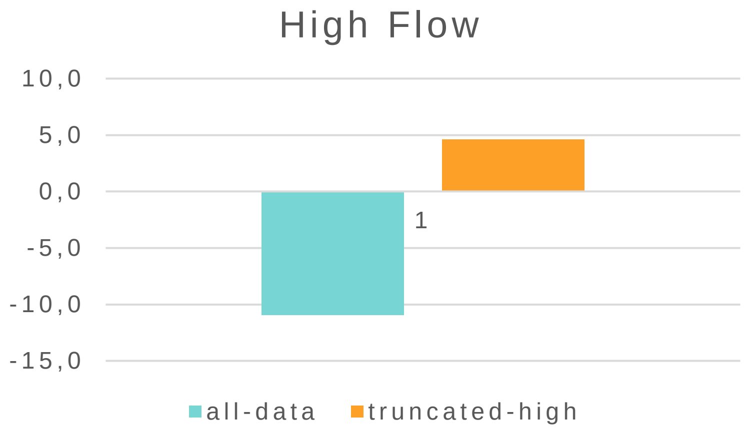


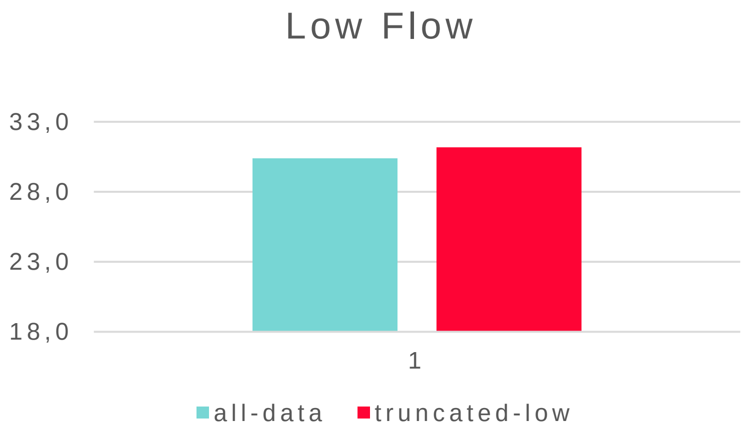
Effects of Extrapolation – Model & Outputs

A PLATE HEAT EXCHANGER, A COMMON COMPONENT IN EV THERMAL SYSTEMS

- Testbench model shown below
- Results shown at right
- Effects of extrapolation are more pronounced at higher flows!







Evaporators & Condensers

THE HIGH AND LOW OF REFRIGERANT CIRCUITS

- Why calibrate and check errors?
- The goal is to get the component model to behave the same way as the measurement data
- In most cases, calibration works well if the input the geometry is accurate
- If calibration fails or produces large errors, we ***must*** inspect the input data!

Evaporators & Condensers

A COMPONENT DATA VETTING PROCESS

Compare geometric properties with a known-good component

↓

If something looks odd, consult the drawing and recalculate it manually

↓

If there is no drawing available, adjust incrementally and recalibrate & recheck errors

↓

When errors are low, stop. If not, continue incremental adjustments then rinse & repeat

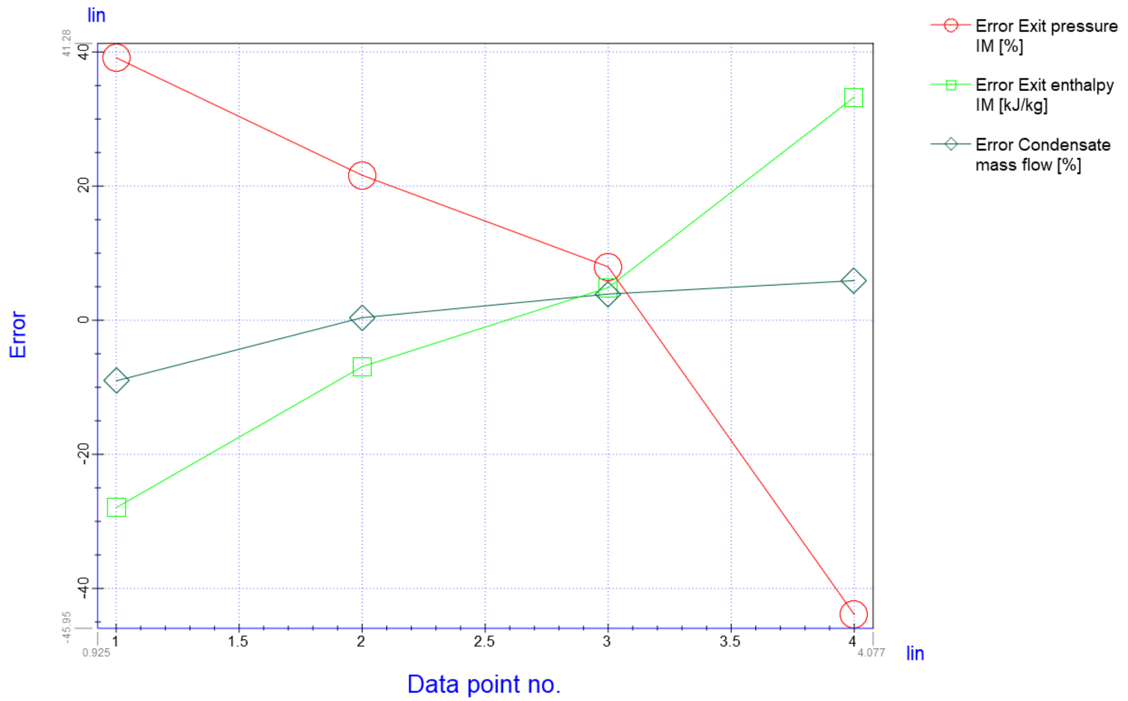
↓

Always try to keep as much original data as possible!

Evaporators & Condensers

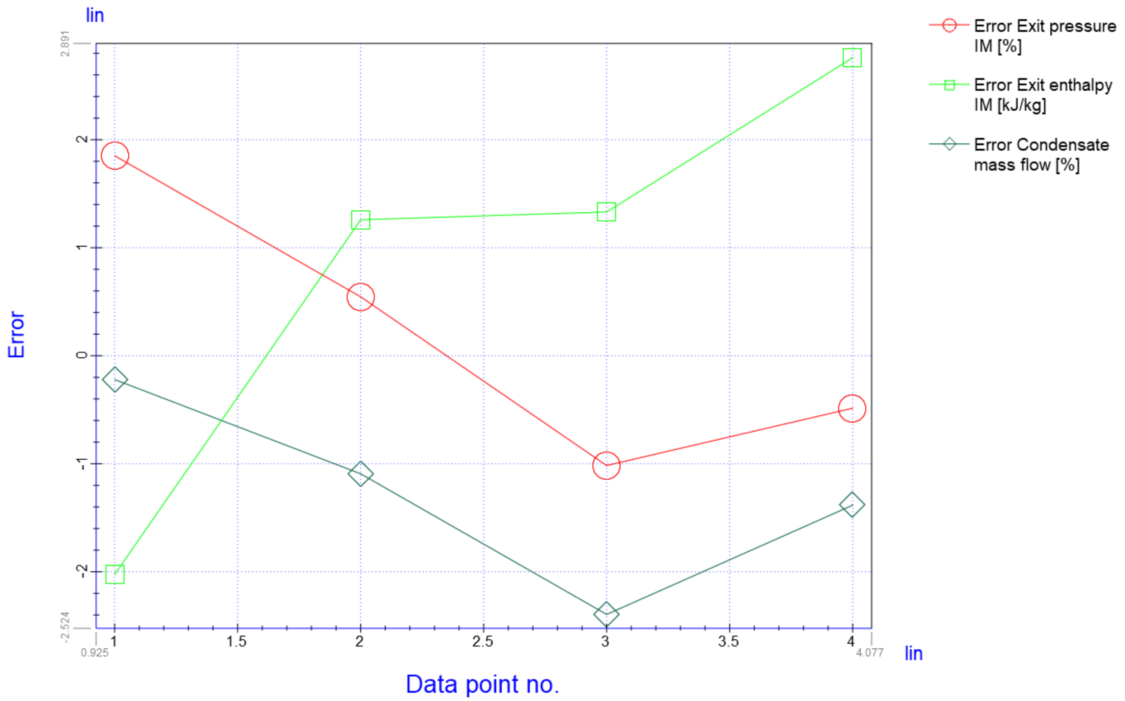
A WHO'S WHO OF THE GOOD AND THE BAD

Evaporator: Error Measurement - Simulation



BAD

Evaporator: Error Measurement - Simulation



GOOD

Evaporators & Condensers

A FEW USUAL SUSPECTS

- Usually, geometry is the cause of high errors and calibration failure
    - Fin pitch and thickness airside (0.3mm is a good guess)
    - Distance between tubes
    - Tube height and wall thickness (0.4mm is a good guess)
- If you can't get a drawing, get a part and start cutting!
- Other areas to check:
    - End tank volume, ensure cross section and core dimensions add up to the specified volume
    - Refrigerant enthalpy can be checked using KULI's property calculator
        - Plot points on the P-h diagram as a sanity check
- The difference between a pipe and a tube is frequently misunderstood. Make sure the input data was provided with the correct understanding in mind.

IMAGE CREDIT: DENSO GLOBAL http://www.globaldenso.com/en/newsreleases/120907-01.html

Compressors

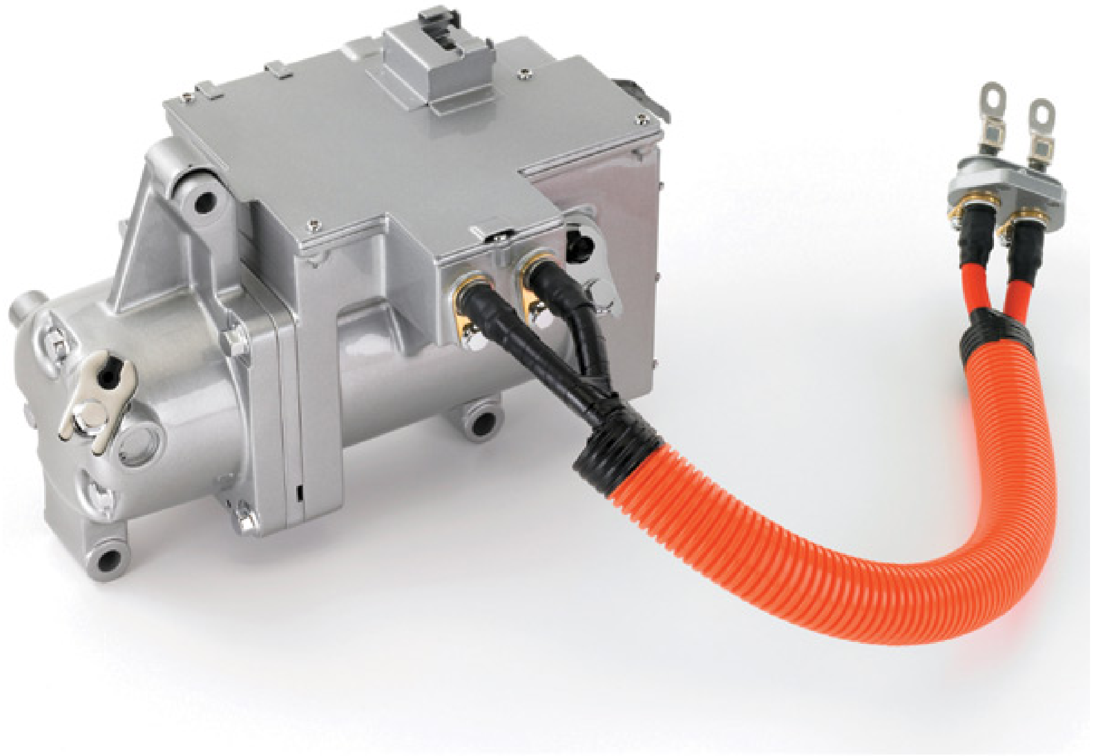
GETTING TO THE HEART OF THE MATTER

- E-Compressor performance data should follow positive-displacement device trends:
  - Low-speed efficiency suffers due to rotor leakage
  - High-speed efficiency suffers from dynamic filling effects
  - Best efficiency is usually somewhere in the middle

- If the curves follow a different trend, find out why!

- Input power is essential for EV range prediction, but often only efficiency is provided. Use the polytropic compressor power equation to define ideal input power:

$$P = \left(\frac{n}{n-1}\right) \cdot P_s \cdot V_d \cdot \left(\frac{N}{60}\right) \cdot \left(\left(\frac{P_d}{P_s}\right)^{\frac{n-1}{n}} - 1\right)$$



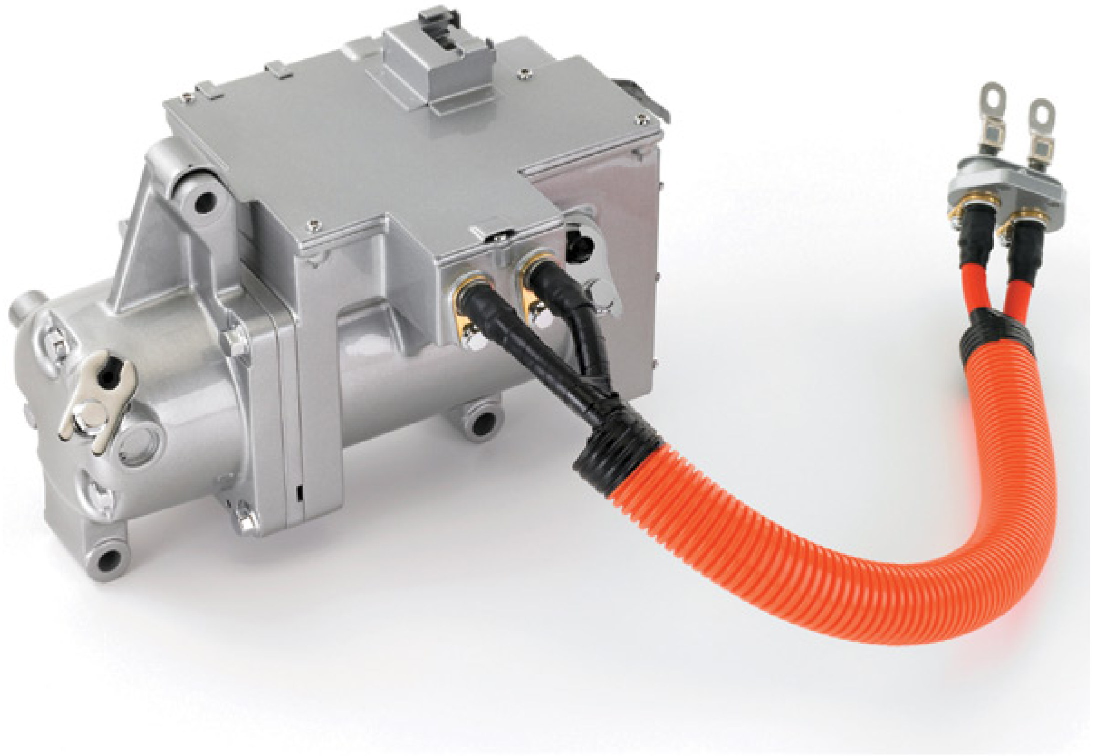
GM, DaimlerChrysler and BMW Two-Mode Hybrid
Electric AC Compressor

IMAGE CREDIT: MOTOR AGE https://www.searchautoparts.com/motorage/maintenance-repair-service-repair/hybrid-c-service

Compressors

IT'S A SPEED THING

- It is tempting to use an optimization target to find the compressor speed that corresponds to a temperature target
- In practice this does not work very well!
- It is *usually* faster to set the compressor speed to a constant value and adjust it manually



GM, DaimlerChrysler and BMW Two-Mode Hybrid
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Plate Heat Exchangers

DYNAMIC SOLVER WORKAROUNDS

- EV thermal systems typically have operational modes in which no coolant flows:
  - Warmup events
  - “Idling”
  - Powertrain during charging

- To model zero-flow modes, the dynamic solver must be enabled…

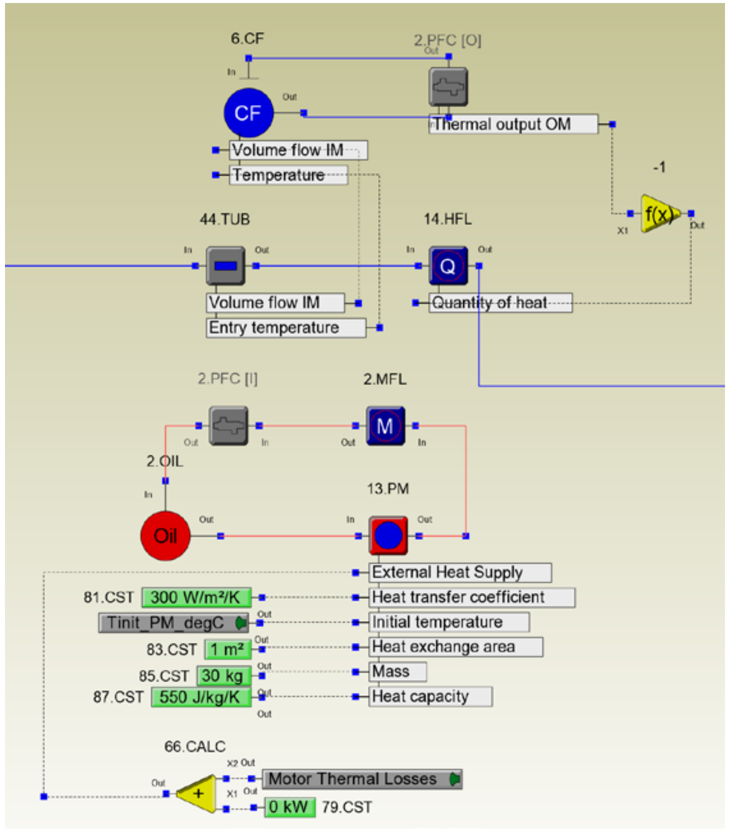
- But the dynamic solver isn’t permitted with plate heat exchangers. What to do?

IMAGE CREDIT: ARMSTRONG FLUID TECHNOLOGY https://armstrongfluidtechnology.com/en/products/abx-brazed-plate-heat-exchangers

Plate Heat Exchangers

DYNAMIC SOLVER WORKAROUNDS

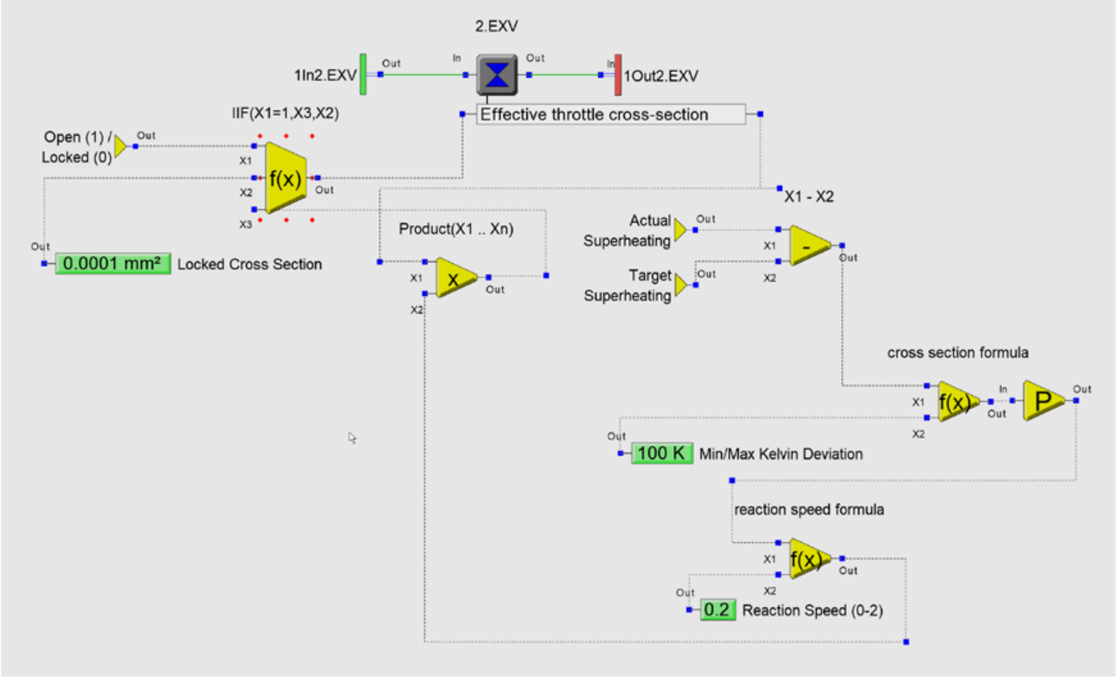
- An example workaround is shown at right using a parallel flow cooler, technique is the same with a plate heat exchanger
- The pressure drop and heat transfer of the heat exchanger are implemented with a tube and a heat flow source, which are allowed in dynamic solver circuits
- The values for pressure drop heat transfer are calculated in a dummy circuit that uses the standard solver
- Dummy circuit values are passed to the dynamic solver via sensors and actuators, using formulas where appropriate



Expansion Valves

TO SHUT OFF OR TO GO WITH THE FLOW

- EV thermal systems commonly contain multiple expansion devices:
  - Coolant chiller
  - Evaporators
- If multiple thermal expansion valves are used, this will cause system instability. What to do?
- Shown at right is an implementation of a TXV with shutoff
- The effective throttle cross section is controlled using a series of formulas:
  - Superheat error is translated into an area, passed to the valve with an actuator
  - Valve can be shut off using a logical operator



Ducts & Tubes

HEAT ON THE PATH OF SOME RESISTANCE

- Minimizing pressure loss in ducts is common design goal when developing a cabin HVAC system. But what about the heat transfer *into* the duct from its environment?

- Heat transfer in ducts can be modeled in two ways:
    - using point masses and conduction paths
    - using a heat source in the airpath

- Blowers tend to operate as constant mass-flow devices in cabin HVAC systems
- As a rule of thumb, heat transfer into ducts from ambient has a greater effect on outputs like cabin temperature than pressure drop inside ducts

- Tubes can be modeled using only 2 points, but results are often unreliable due to excessive interpolation

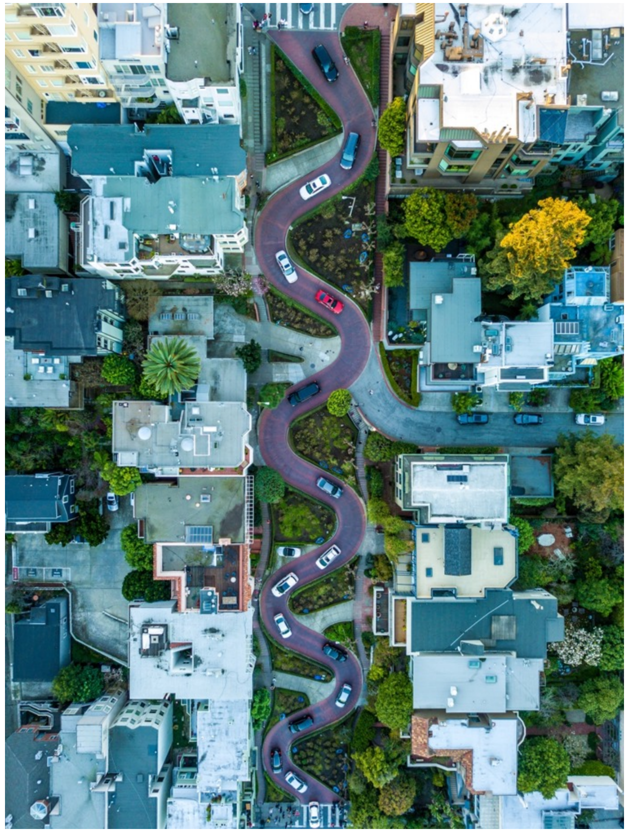
- 3 points are better, parametric equations are ***best!***

System Modeling

Parameter Variation & Optimization Targets

GOLDILOCKS IS BACK AND FORTH AND BACK AGAIN

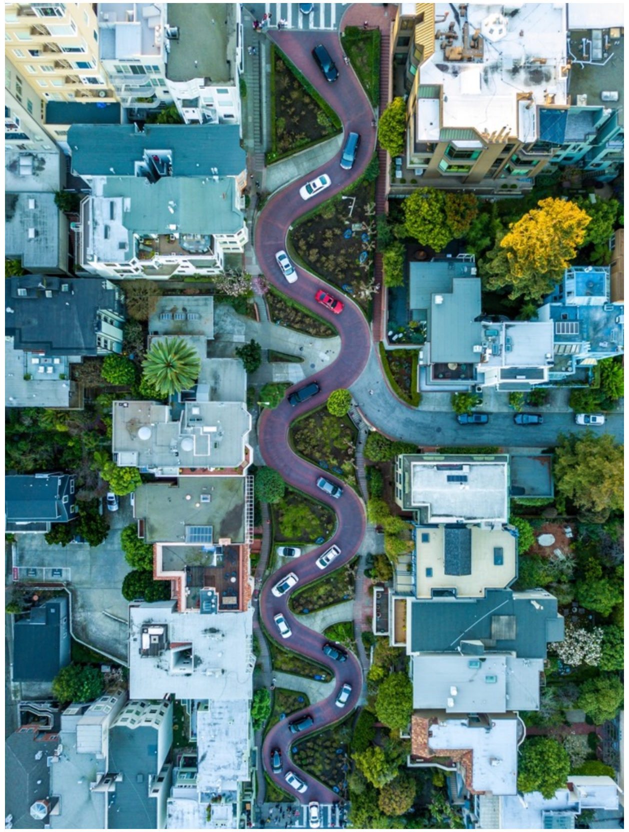
- Running parameter variations or optimization targets in refrigerant loops is not straightforward
- If one point doesn't solve then you are waiting for a long time for no results, not knowing where the problem is!
- Restricting the range of variation can help sometimes
- Manual variation is *usually* best



Subsequent Operating Points

FIRST THIS, NOW THIS

- The KULI solver initializes the refrigerant loop with default values
- When the first operating point finishes, the solver initializes the second operating point at the state in which the first point solved
- If this state is too far off of the solution for the second point, the solver may fail or produce an unrealistic result
- To avoid this problem:
  - Make small incremental changes in simulation parameters for subsequent operating points
  - Limit the number of parameters that change from one point to the next to one or two *at most*

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Questions?

A STARTING POINT

- What should I look for when using the KULI refrigerant property calculator to verify evaporator and condenser calibration?
    - On P-h diagram plots:
        - Evaporator inlet should be under the dome
        - Condenser inlet should be to the right of the dome
- When using the polytropic compressor power equation to define ideal input power, what is an appropriate value for *n*, the polytropic expansion coefficient?
    - For r134a, n = 1.08 – 1.10
- Does a tube have fins?
    - NO!
    - **<u>Remember</u>**: *Pipes go inside tubes, fins go inside pipes*

Thank You

With sincerest acknowledgements to:
Petr Kamenksy @ MAGNA, for elucidating many of the methods shown in this presentation

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