

Offroad Thermal Management: Tractors

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JOHN DEERE



Agenda

Intro and Tractor Cooling Systems

How to Achieve 100% DFPY

What's Next?

John Deere Factory

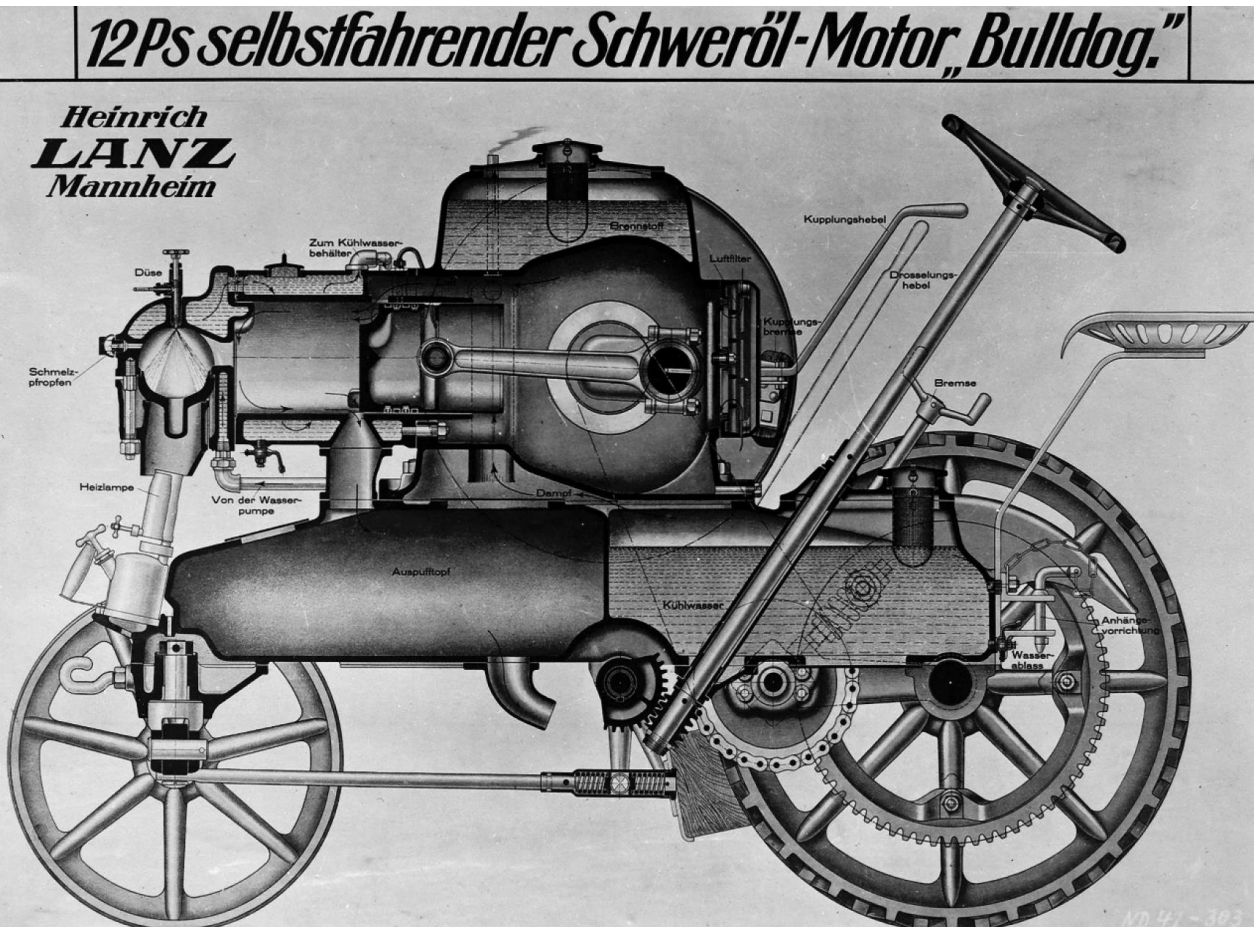
Mannheim, Germany

- John Deere's largest factory outside North America
- Products: 6M/6R Series tractors
- Two million tractors since 1921
- 4- and 6-cylinder, 90 to 250 hp
- 2022 production: approx. 40,000 units
- 3,250 employees (JD worldwide: 79,225)

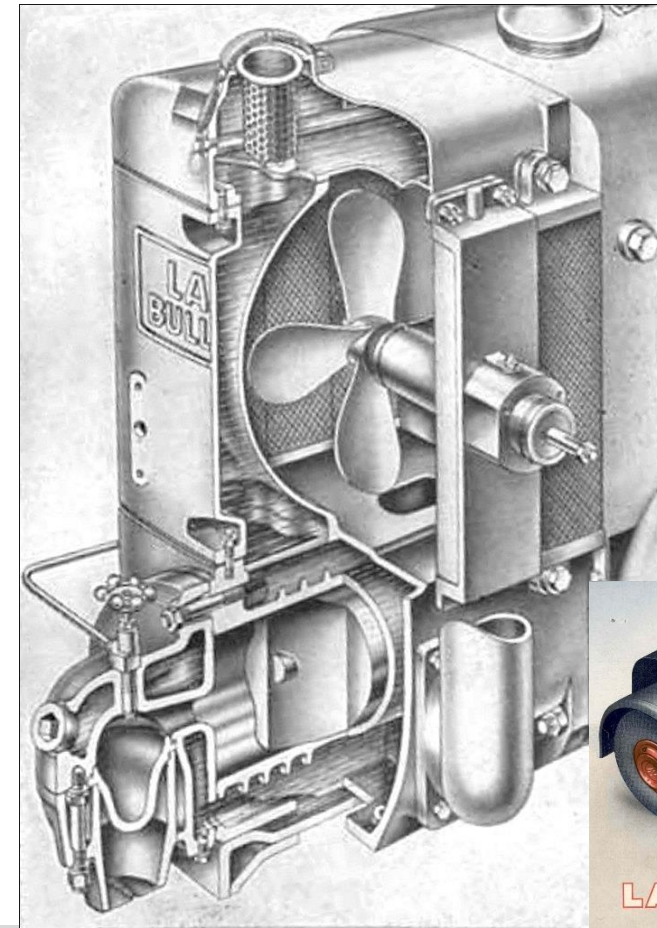


Tractor Cooling - The Past

Evaporative Cooling



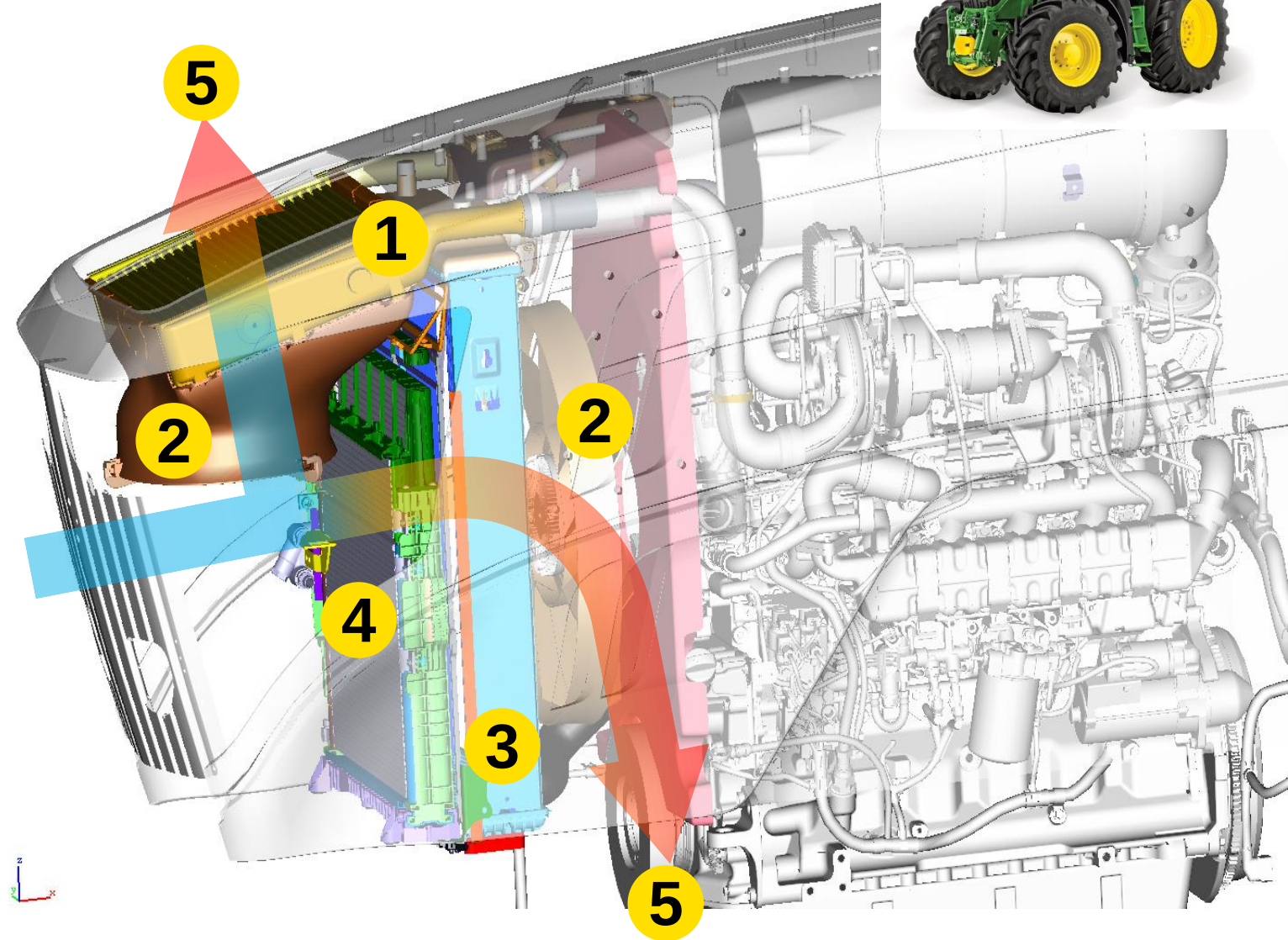
Thermosiphon Cooling



Current Tractor Cooling System: 6250R



- 1** Charge Air
- 2** Fans
- 3** Radiator
- 4** Oil, Fuel, ACC
- 5** Air Path

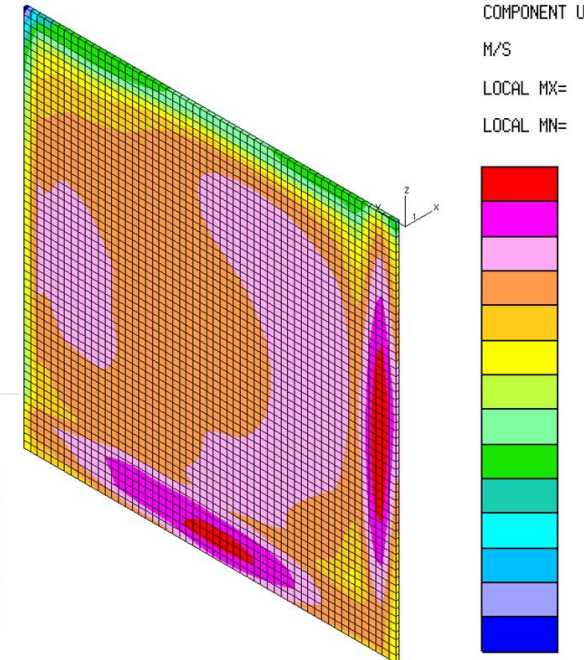
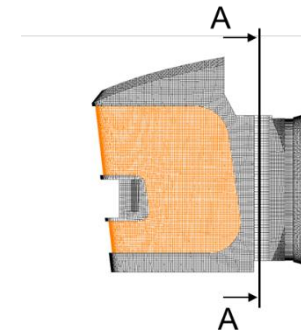
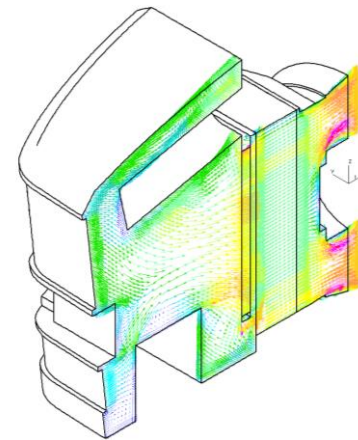
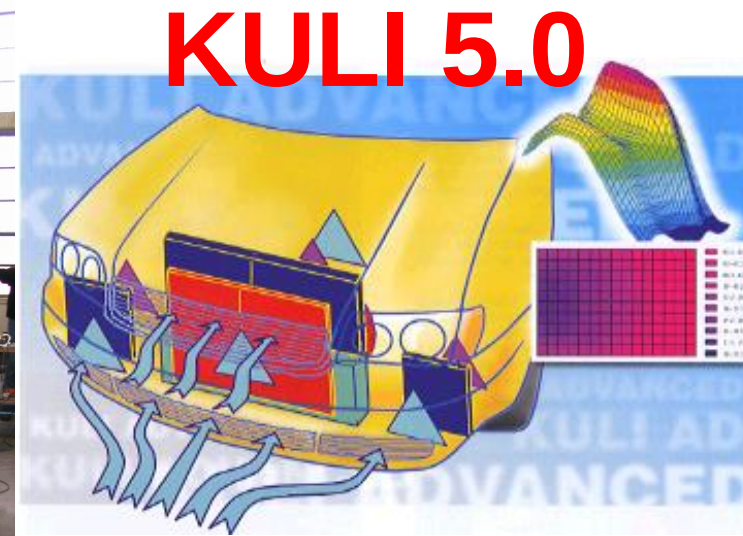


Ultimate Analysis Goal

$$\text{Design First Pass Yield (DFPY)} = \frac{\# \text{ Cooling Lab Tests ok}}{\# \text{ All Cooling Lab Tests}} = 100\%$$

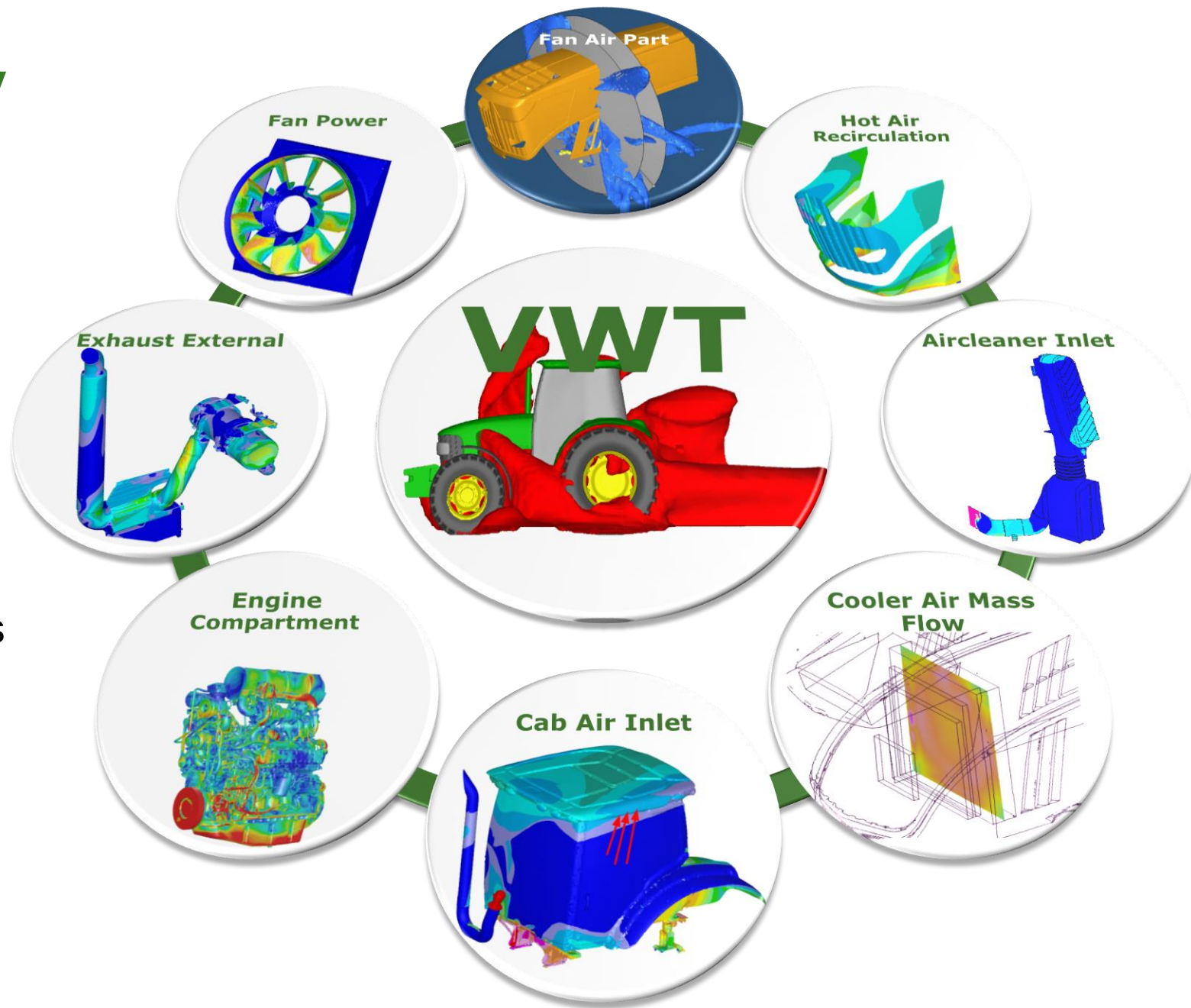
Early 2000s Analysis Tools

- KULI for thermal analysis.
- CFD limited capability, mostly airflow distribution.
- Hybrid approach, airflow determined in “rocket” (SAEJ1339).



Analysis Tools Today

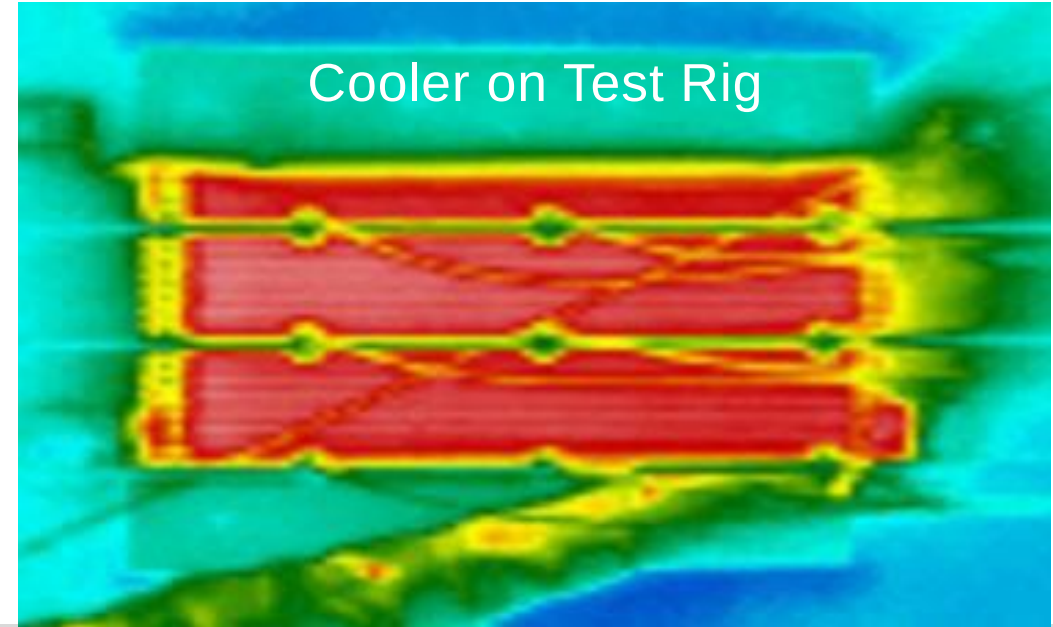
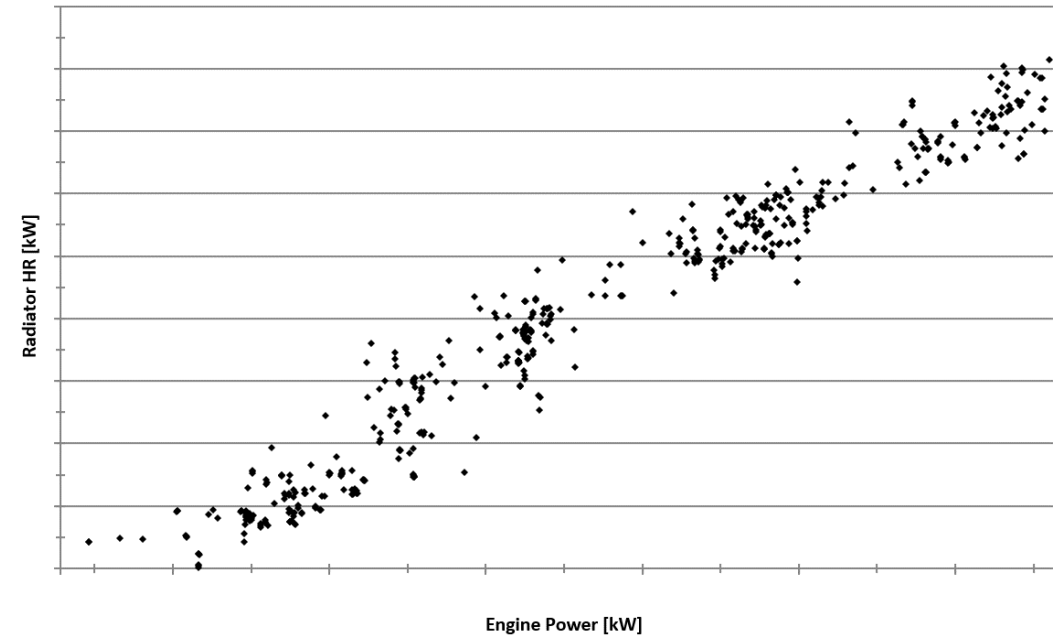
- KULI for thermal analysis.
- CFD evolved to airflow, recirc and more in the virtual windtunnel (VWT).
- More compute power (Beowulf cluster, cloud) was the CFD door opener.



Analysis Input Data

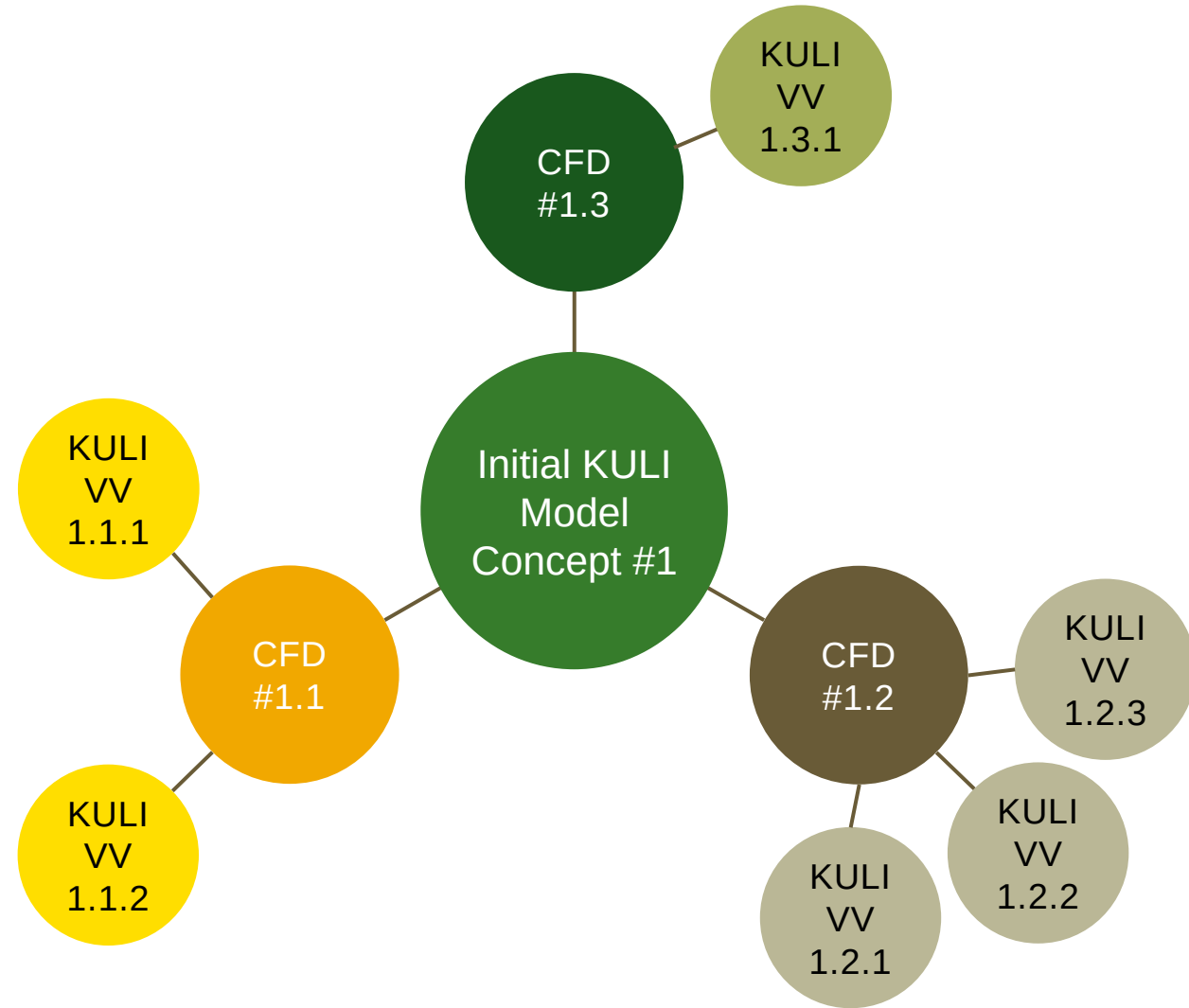
- Analyst needs to understand input data quality and its variation.
- Heat rejection from engine test rigs or simulation, same for other subsystems.
- Heat exchanger (HX) data often provided by supplier.
- If HX data not available or too narrow ranges (no extrapolation!), we measure component data in JD labs.

Radiator Heat Rejection over Engine Power



Cooling System Analysis Process

- Combination of KULI + CFD.
- Initial KULI model for rough sizing.
- CFD for isothermal airflow.
- Virtual Verification (VV) KULI model calibrated to CFD airflow.
- KULI VV could be one or many per CFD case.
- Best performing KULI VV model => starting point for the next iteration – virtual or physical.



Windtunnel Verification

- Already the first cooling system developed by the KULI+CFD process worked fine in the lab.
- Since then, no more hardware iterations were required.
- 100% DFPY for over 15 years!
- Physical testing to identify new failure modes – but no iterations.
- Frontloading of new failure modes to the next analysis sprint.



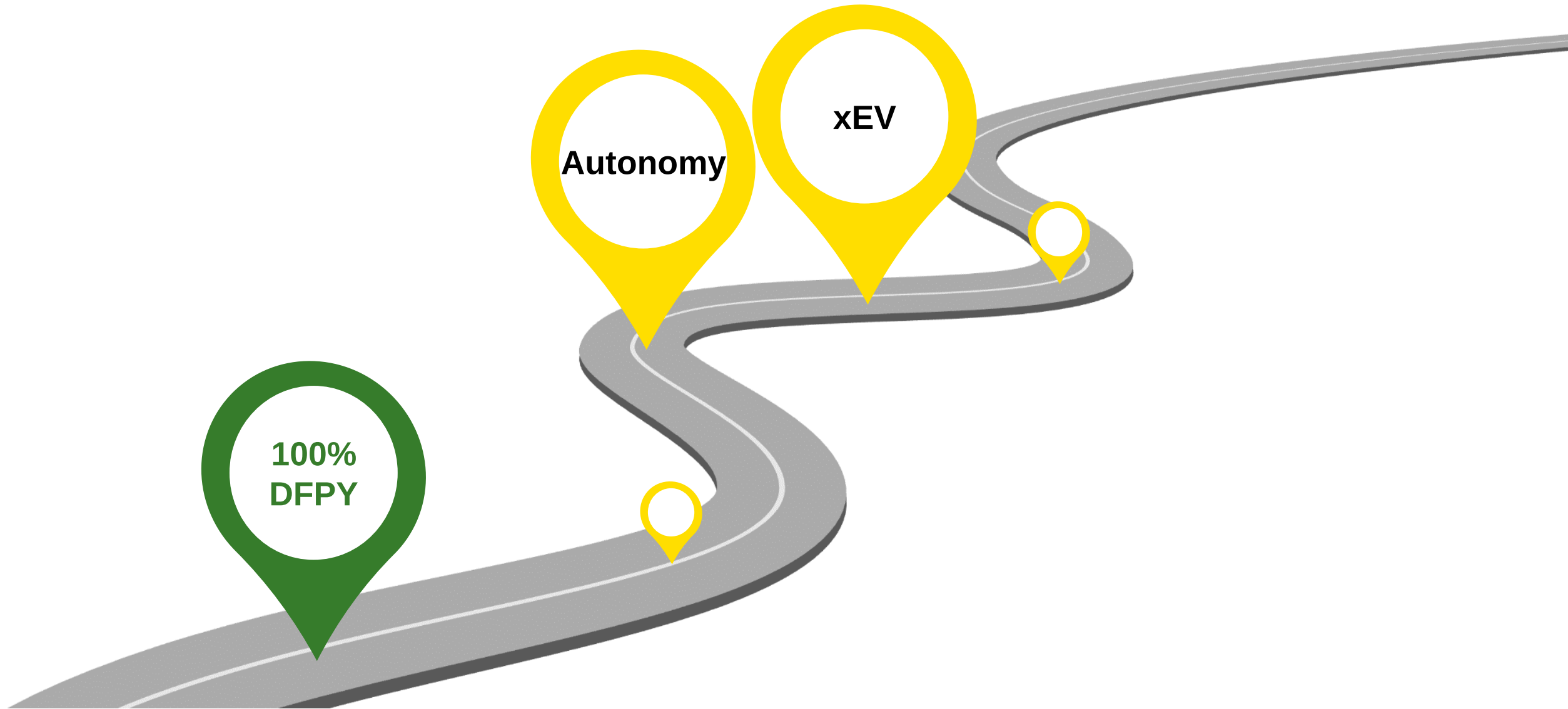
Correlation

- Last analysis step is correlation.
- Analyst checks input data correlation and systematic model correlation.
- Model correlation means heat rejection, flow, fan speed of the very test is the input for a KULI VV model checking the offset to the measured temperatures.
- Offsets trigger model improvements.
- Systematic capability + input variation = upfront prediction capability.

Tractor #1				
		Test Condition #1		
Channel		Test	KULI	dT
Ambient	°C	46.2	46.2	Input
Fan Speed	rpm	2327	2327	Input
Rad T _{in}	°C	103.4	103.9	+0.5 K
CAC T _{out}	°C	73.6	73.0	-0.6 K
TOC T _{in}	°C	85.5	86.0	+0.5 K

Tractor #2				
		Test Condition #1		
Channel		Test	KULI	dT
Ambient	°C	46.0	46.0	Input
Fan Speed	rpm	2422	2422	Input
Rad T _{in}	°C	108.9	108.9	±0.0 K
CAC T _{out}	°C	64.9	64.4	-0.5 K
TOC T _{in}	°C	78.1	75.6	-2.5 K

Next Tractor Thermal Challenges



Autonomous Tractors

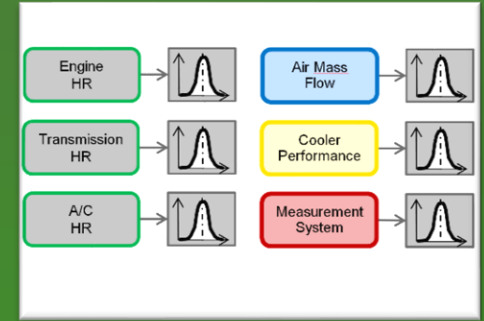
- Full autonomy means the operator is not necessarily nearby, unattended operation.
- Could be single vehicle or a swarm.
- To benefit from unattended operation, limited user interaction preferred.
- Swarm + unattended means more vehicles need more uptime.



Autonomy: Reliable Performance

- Swarm could mean lots of vehicles. Each must meet performance goals.
- Squeezing is tough.
- Knowing input data variation and KULI parameter variation (PV), shift is possible.
- All vehicles fulfill the performance expectation: Robust Design.
- More statistical KULI analysis/DOE/EVA.

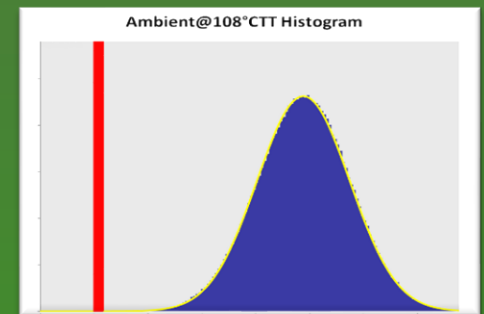
Input Variation



CFD + KULI PV Analysis

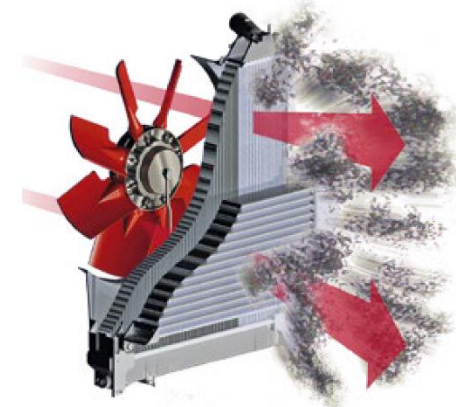
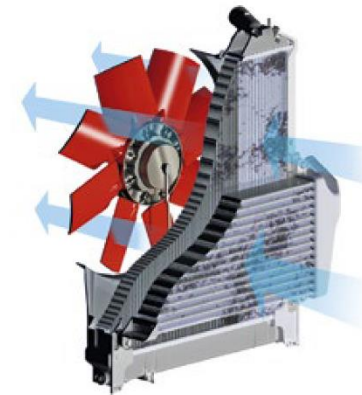


Robust Design



Autonomy: Maintenance

- Today regular maintenance required, e.g. because of debris accumulation.
- Unattended operation or swarm forces predictive or automatic maintenance.
- Predictive example:
 - KULI VV => realtime model on vehicle => expected temperature levels => sensor reading higher => plan cleaning.
- Automatic example:
 - Replace manual cleaning by reversible fan or rotary screens. KULI + Discrete Elements?

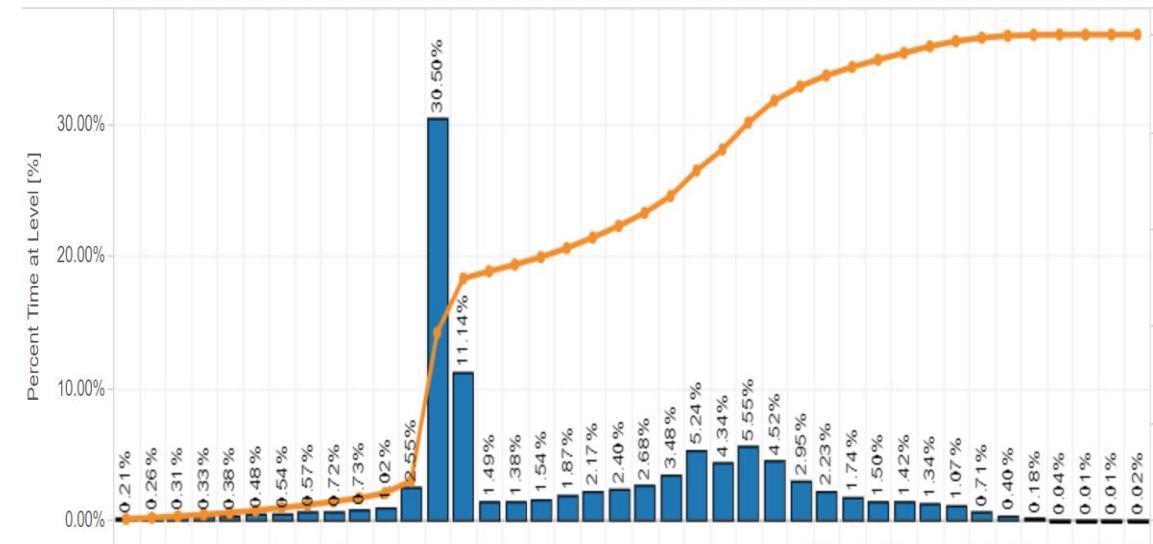


Autonomy: Telemetry JDLINK

- More telemetry use for health monitoring and to supervise autonomous vehicles.
- Acceptance criteria today often empirical, with telemetry we see performance “live”.
- Analyst becomes data wrangler.
- Transform “raw” data into insights about cooling performance at certain applications.
- Derive duty cycles and use for transient KULI analysis.

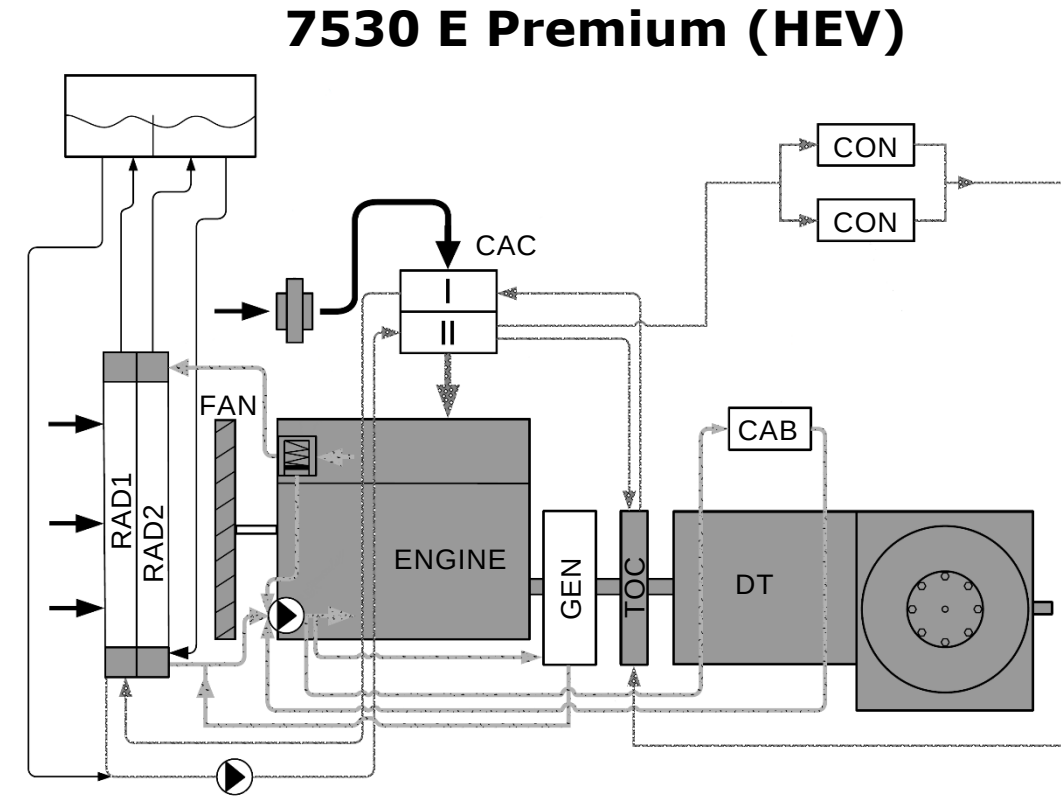


Coolant Temperature - Time at Level Histogram



xEV Inner Cooling Layout

- Valves, pumps, controls => like a hydraulic circuit.
- Availability (HY much better) and modeling of valves for coolant circuits.
- High speed analysis parallel to development to track line/interface changes (impeller pumps, parallel flows).
- Cooling system plant model for controls development.



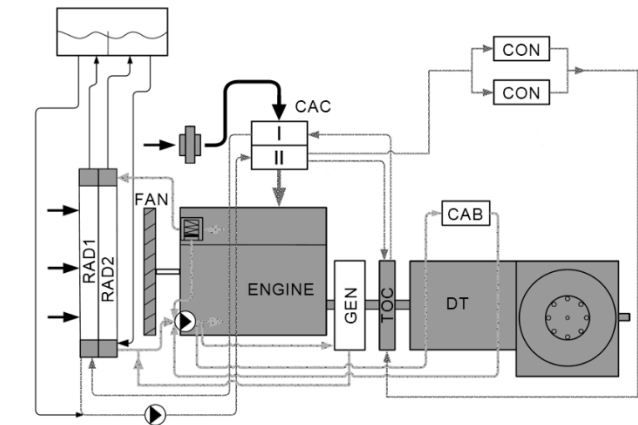
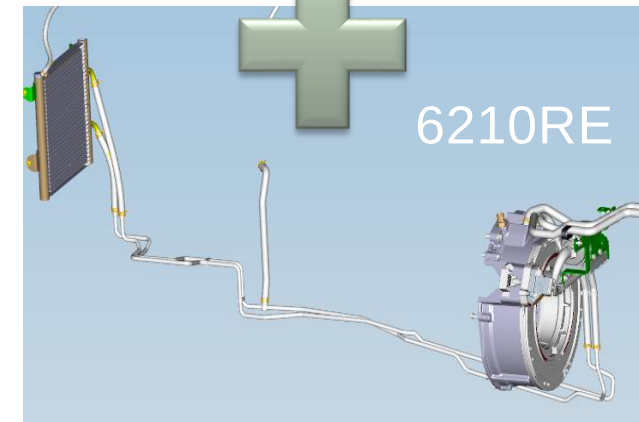
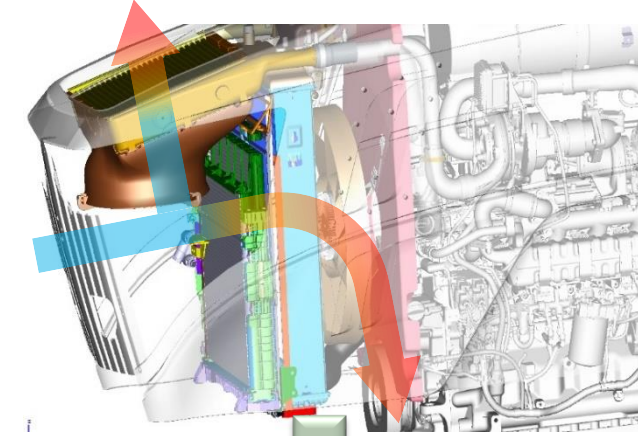
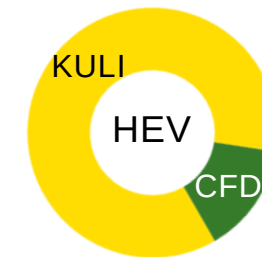
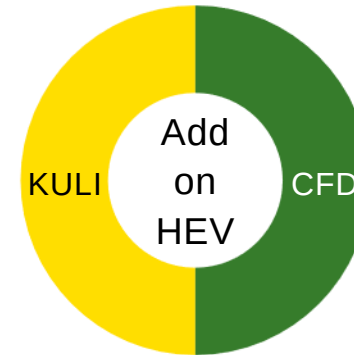
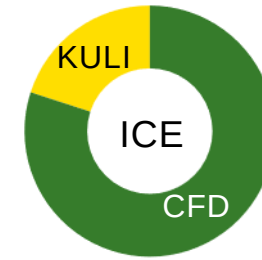
xEV – Refrigerant Circuits

- Cabs could become standalone (part time).
- Electric or thermal energy storage.
- Cool batteries and/or electronics.
- Heat pump application in case of BEV.
- Need for analysis of refrigerant circuits is increasing.



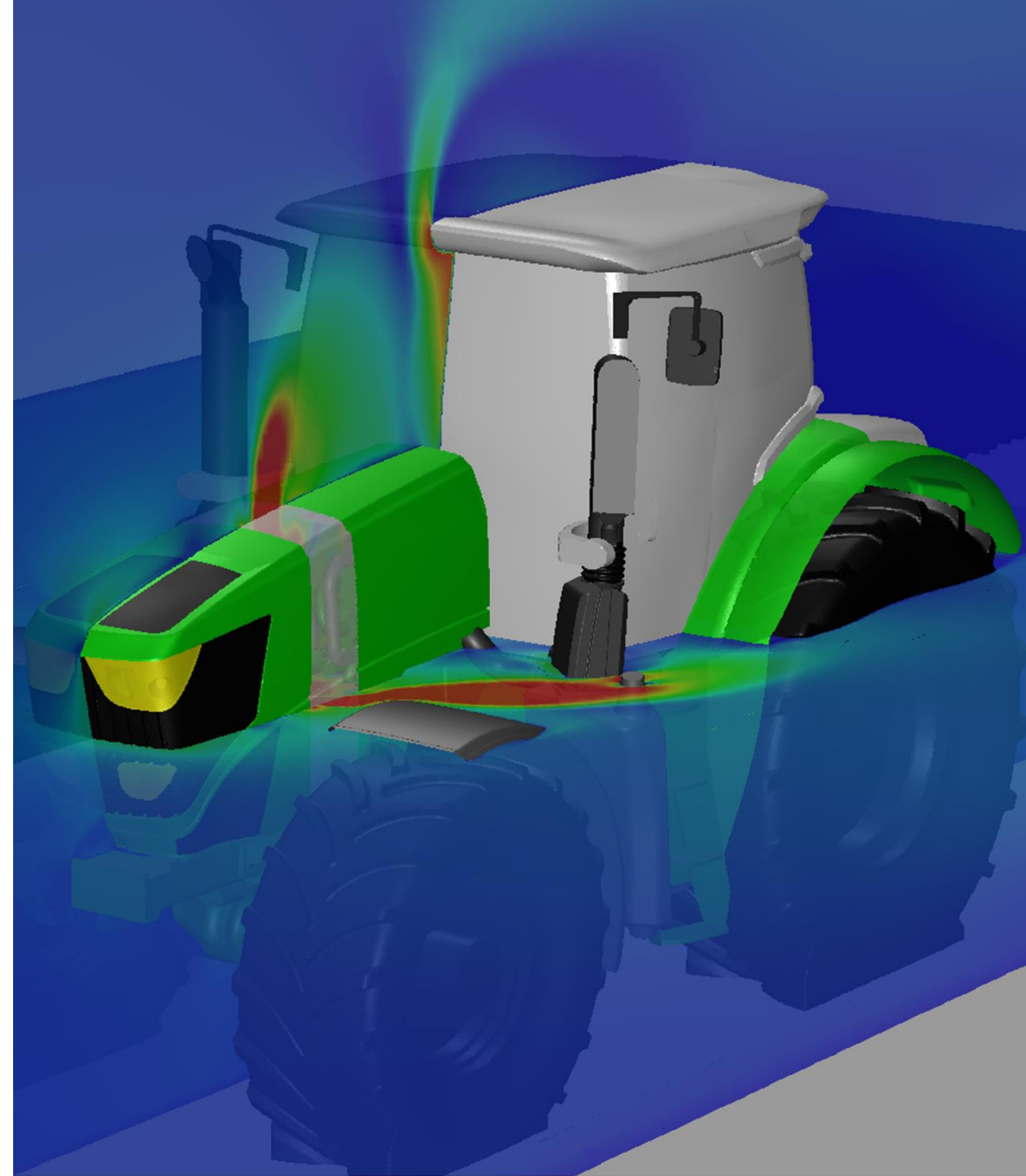
xEV – Tool Impact

- Analysis effort varies between tools as well as overall depending on system layout.
- ICE cooling CFD effort is dominant.
- HEV effort depends
 - Integrated into an indirect system.
 - Add on is worst case.
- BEV comparable to indirect HEV.
- For indirect HEV and BEV tractors, less isothermal CFD and more KULI usage.



Summary

- Tractor cooling systems evolved from simple to today's complexity.
- KULI + CFD + good input = 100% DFPY for over 15 years!
- Next tractor thermal challenges are Autonomy and xEV.
- More HVAC, ROM, complex inner circuits, Robust Design => increased need for thermal analysis.
- What's your next challenge?





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