

HIGH CAPACITY | PRECISION | RELIABILITY

Plasser & Theurer

ECS Simulation Conference 2023

Cooling system optimization for Track Inspection Vehicles (TIV)

DI Markus Raup | May 2023



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- Introduction
 - Track Inspection Vehicle layout
 - Power train concept
 - Power pack cooling system
 - Traction cooling system
- Simulation model
 - Track data & driving simulation
 - Steady state simulation model (data, calibration, ...)
 - Transient simulation model (data, calibration, ...)
- Results
 - Steady state simulation model
 - Transient simulation model
- Summary & Outlook



Cooling system optimization for TIV

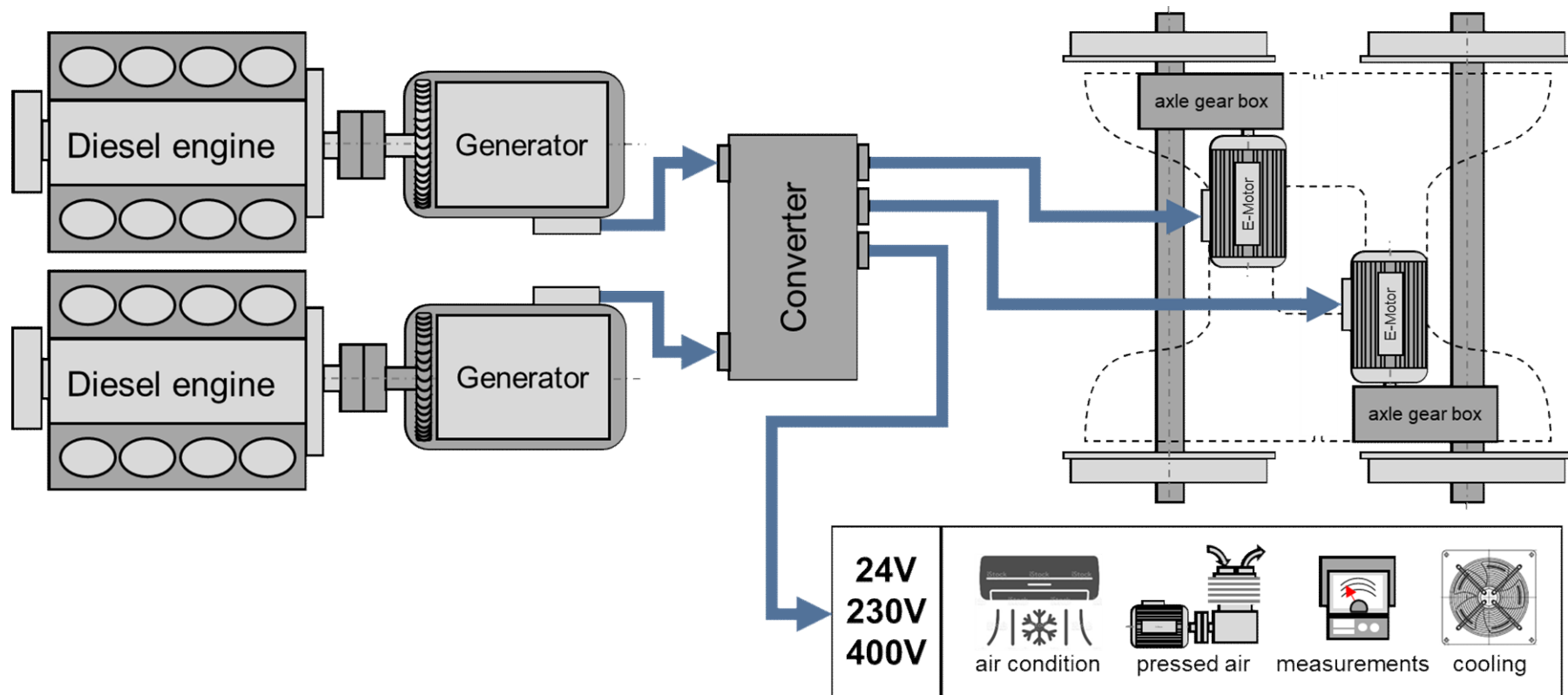
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Track Inspection Vehicle layout



Cooling system optimization for TIV

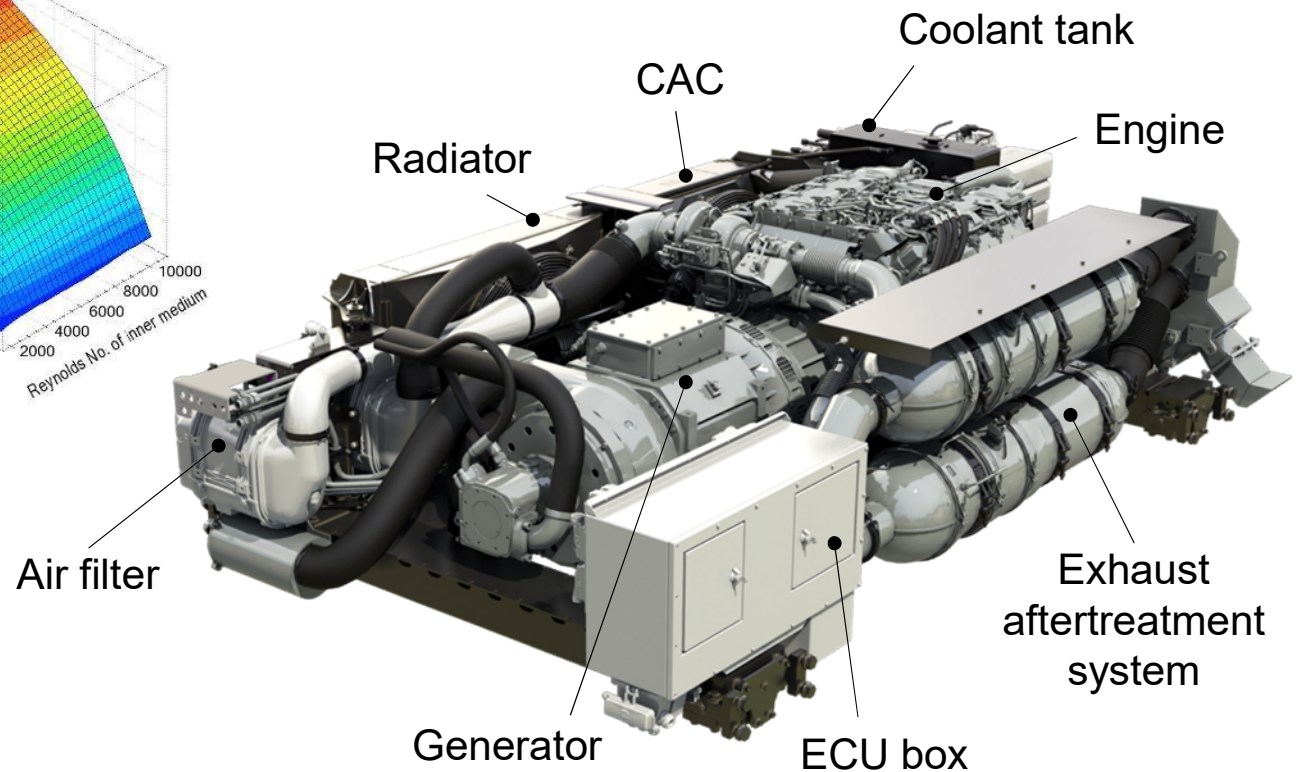
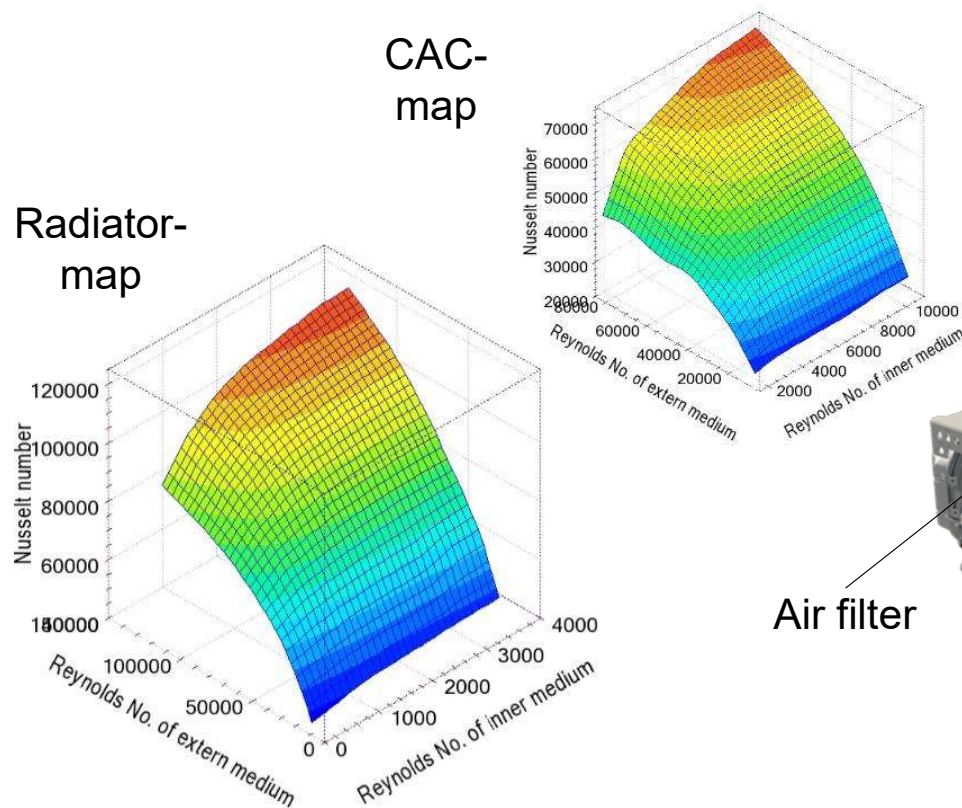
Power train concept – Diesel electric



Cooling system optimization for TIV

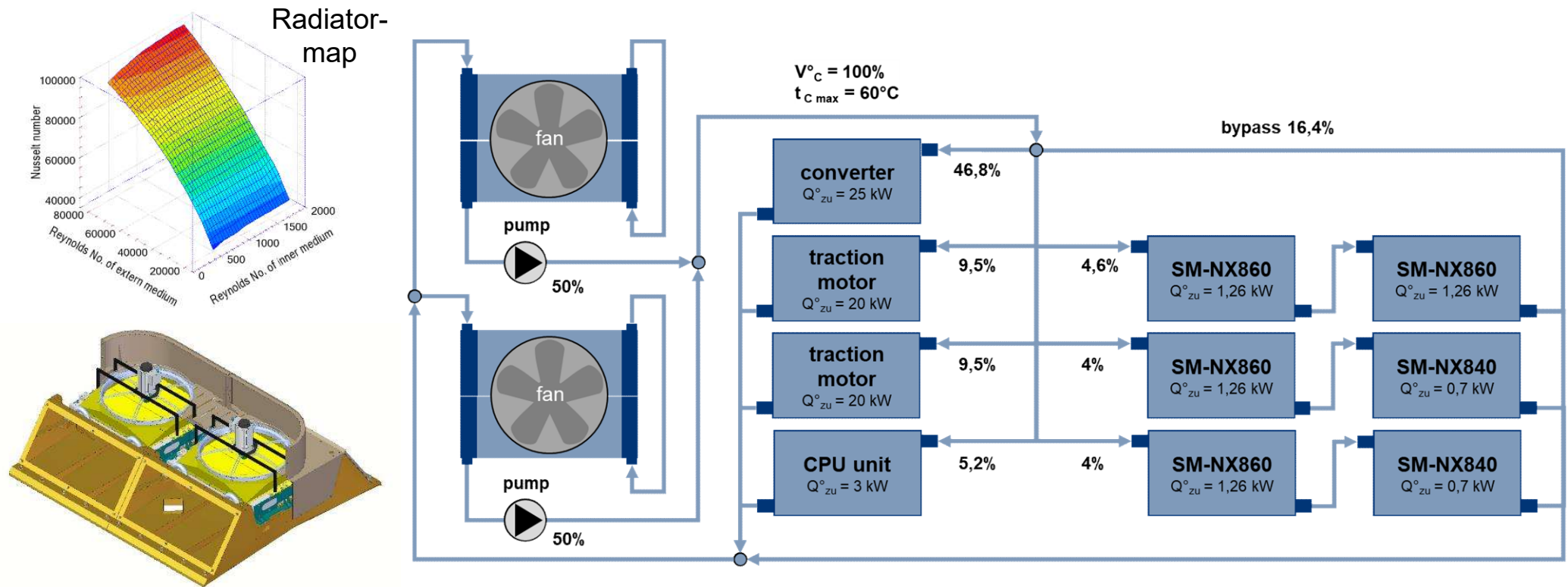
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Power pack cooling system



Cooling system optimization for TIV

Traction cooling system



Cooling system optimization for TIV

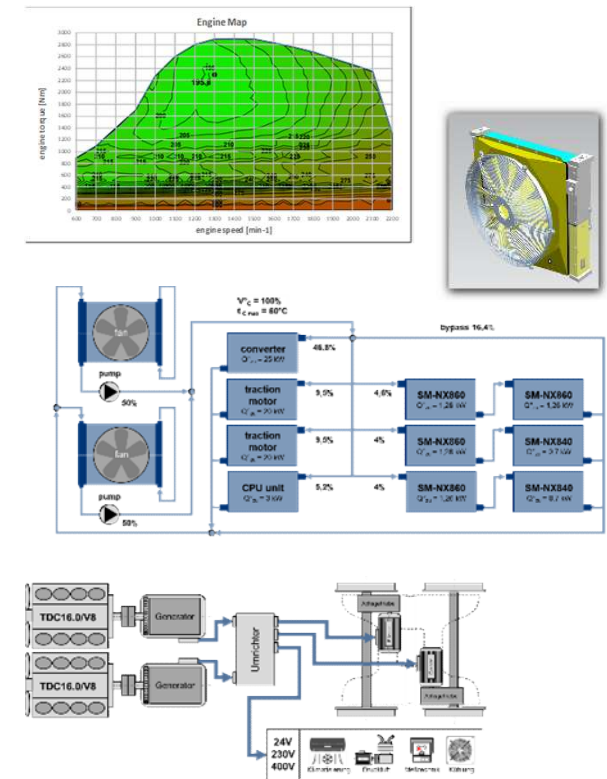
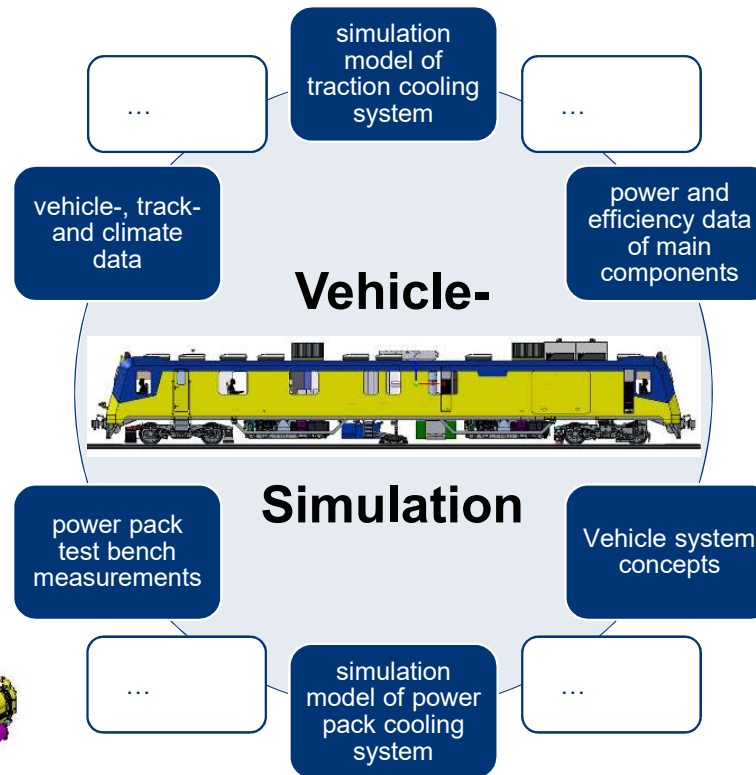
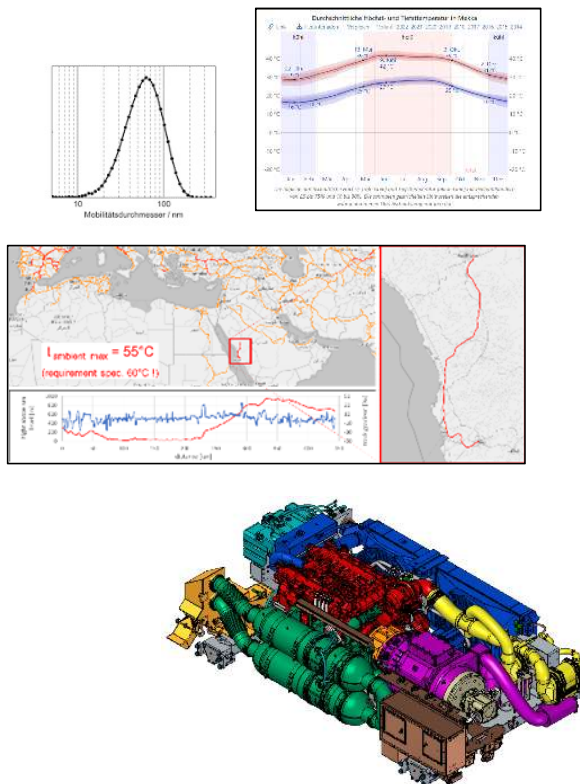
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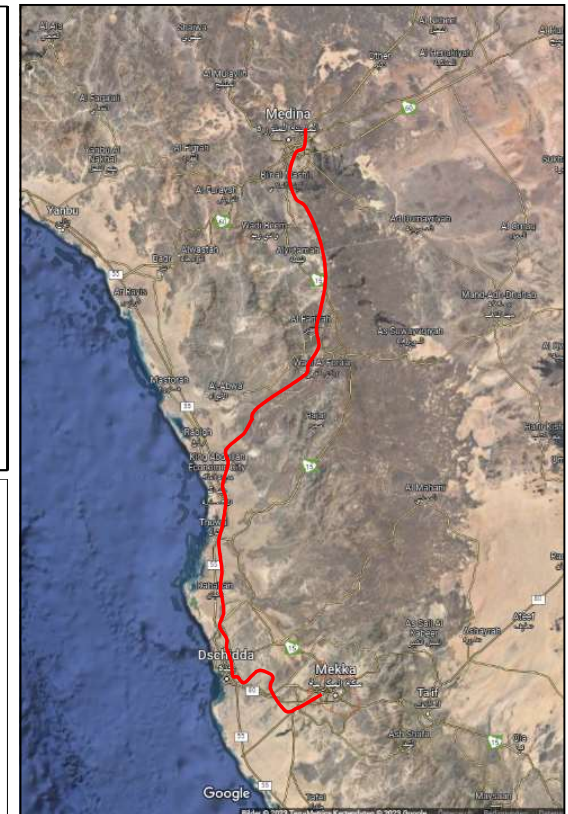
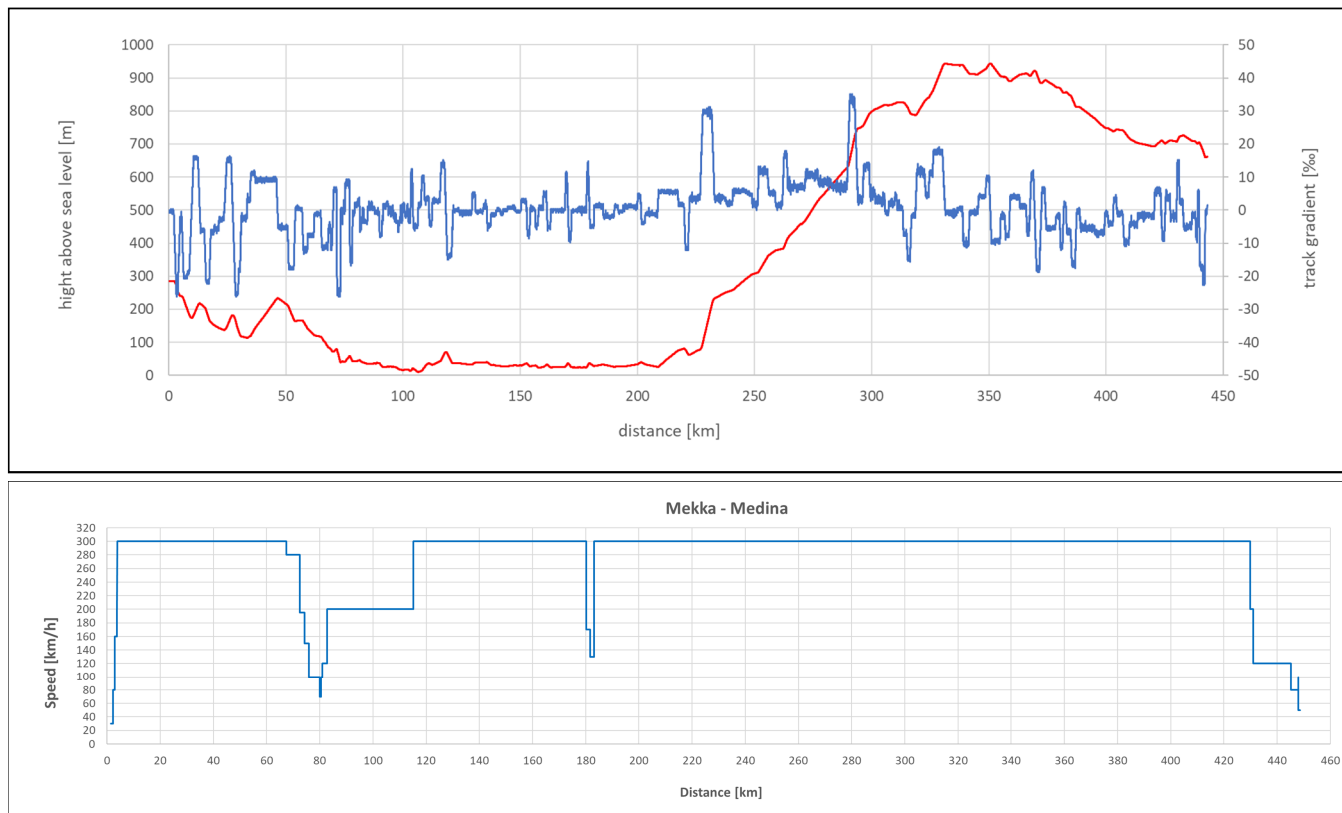
Simulation model



Cooling system optimization for TIV

Track data & driving simulation

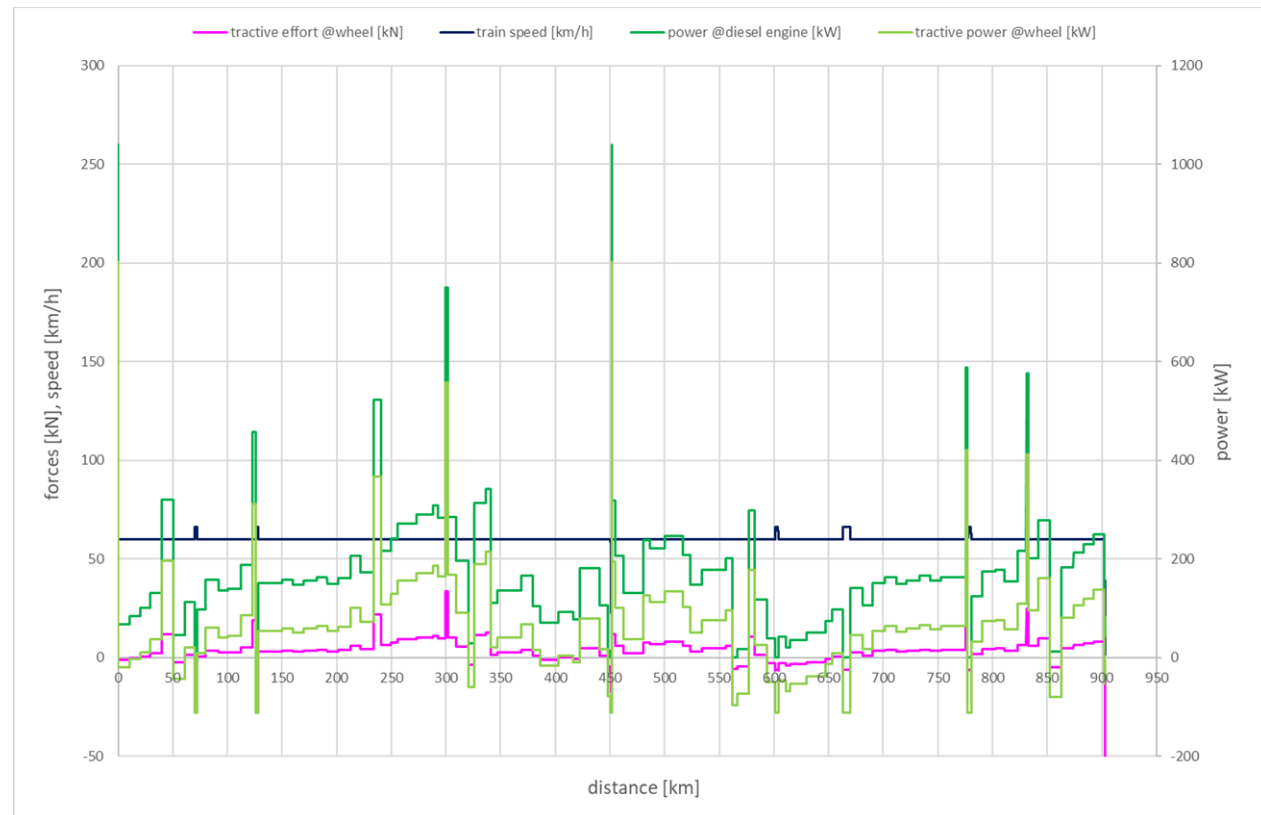
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Cooling system optimization for TIV

Track data & driving simulation

target speed = 60 km/h

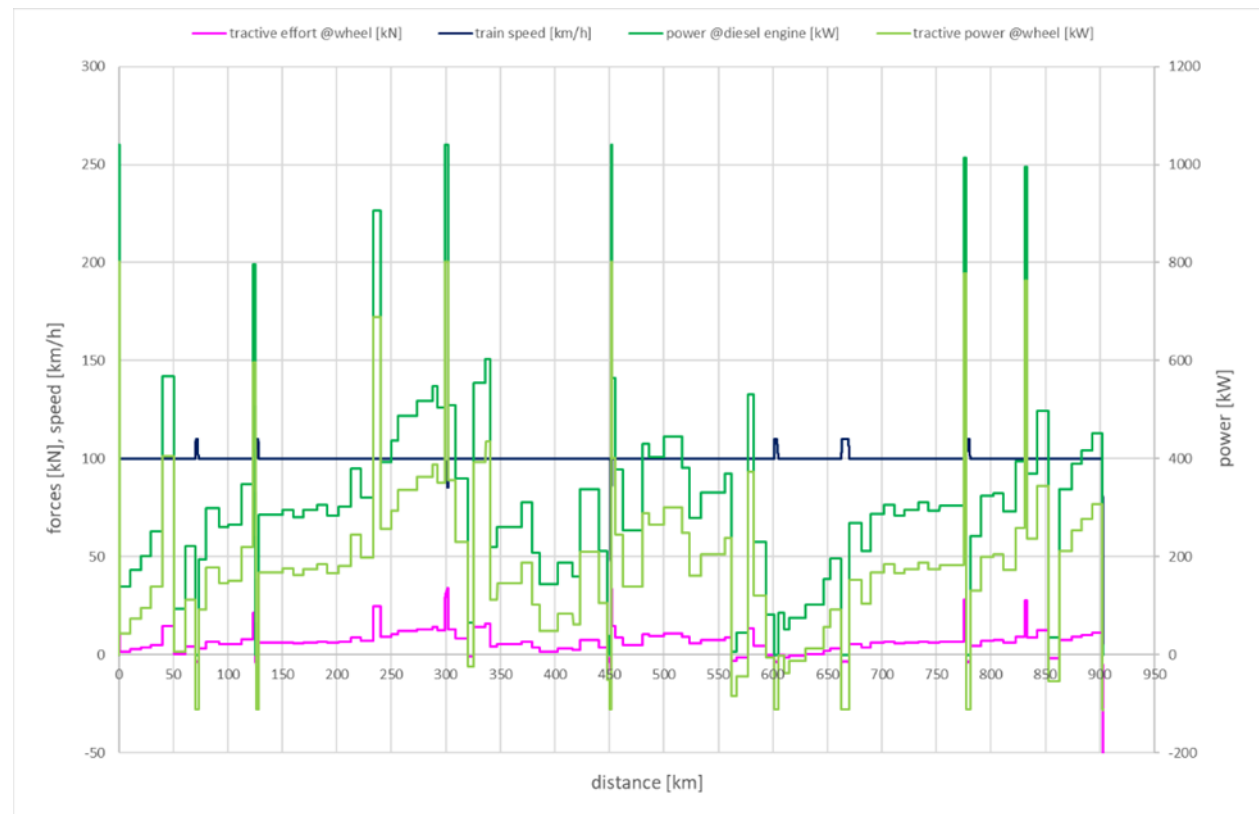


Cooling system optimization for TIV

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Track data & driving simulation

target speed = 100 km/h



Cooling system optimization for TIV

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Track data & driving simulation

target speed = 160 km/h



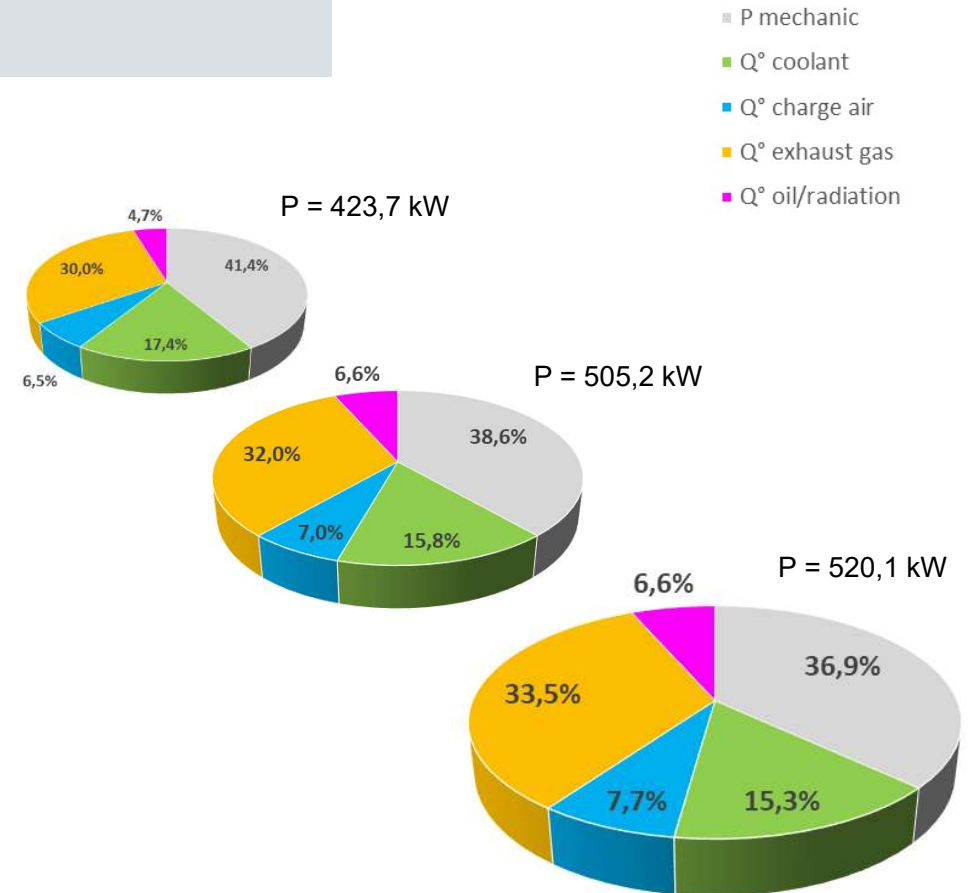
Cooling system optimization for TIV

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Steady state simulation model

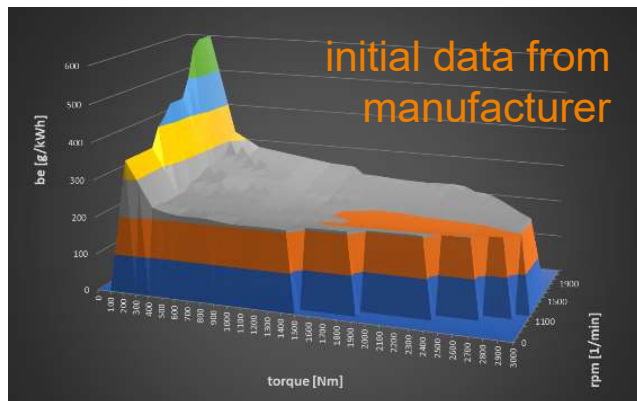
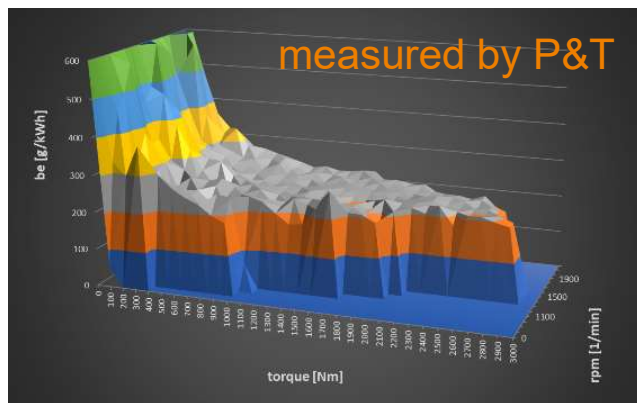
Original data from manufacturer :

engine power	520,1	36,9%	505,2	38,6%	423,7	41,4%	kW
engine torque	2365,0		2680,0		2890,0		Nm
engine speed	2100		1800		1400		min-1
spec. Fuel consumption	227		217		202		g/kWh
no. cylinders	8		8		8		-
no. injections	8400		7200		5600		Inj/min
fuel consumption	118,1		109,6		85,6		kg/h
injection quantity	234,2		253,8		254,7		mg/Inj
calorific value Diesel	43		43		43		MJ/kg
total energy input	5076,6		4713,7		3680,2		MJ/h
Q°_ges	1410,2	100%	1309,4	100%	1022,3	100%	kW
Q°_coolant	216,0	15,3%	207,0	15,8%	178,0	17,4%	kW
Q°_charge air	108,9	7,7%	91,5	7,0%	66,3	6,5%	kW
Q°_exhaust gas	472,4	33,5%	419,0	32,0%	3,1	30,0%	kW
Q°_oil/radiation	92,8	6,6%	86,7	6,6%	47,6	4,7%	kW



Cooling system optimization for TIV

Steady state simulation model



Difference between measured and initial data

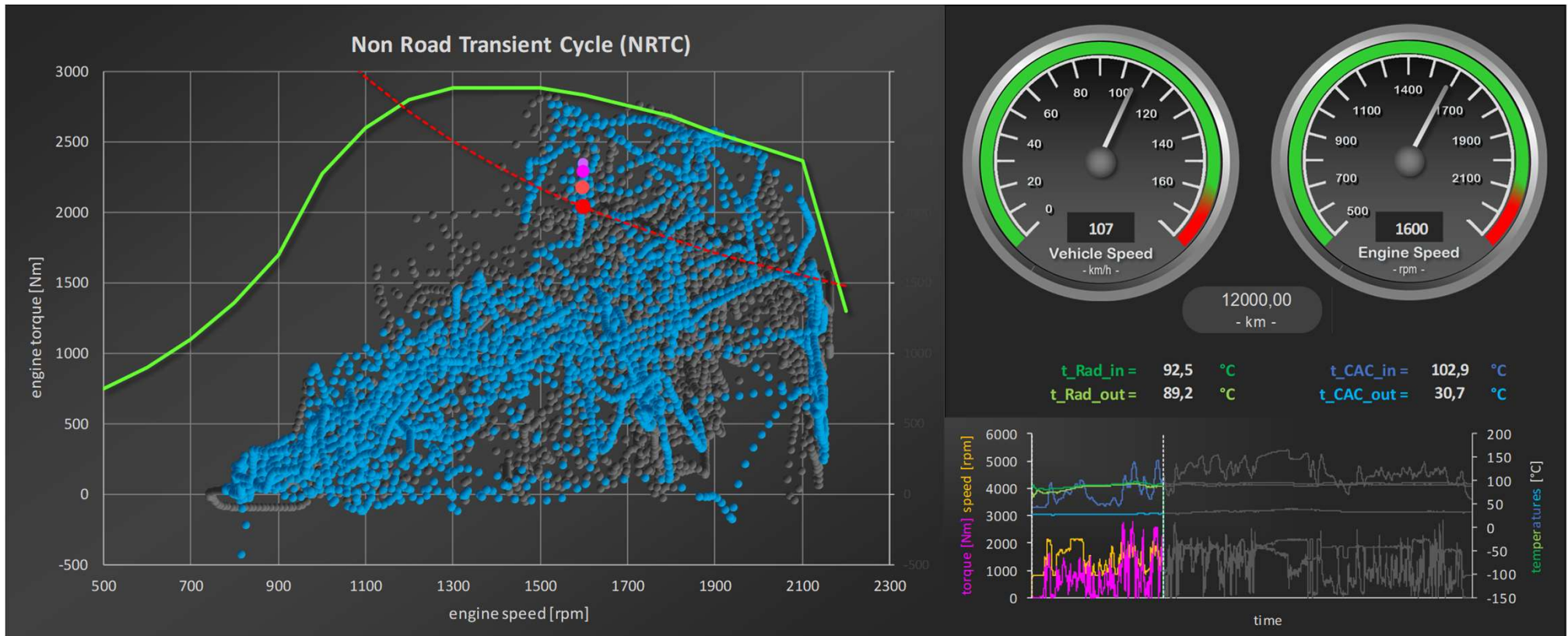
diff. be	0	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200
0																
100																
200		-17,21	-4,63	-7,69	9,85	-1,09	-12,46	10,90	-9,41	-7,04	-15,30	-22,49	-1,00	-12,65	-23,38	
300		26,23	8,98	-10,01	1,30	5,30	-5,58	15,49	13,72	-6,17	-14,37	-21,09	-12,08	-27,50	-21,02	
400			24,59	4,92	6,21	0,97	19,09	28,11	25,82	15,38	13,39	11,09	11,46	16,42	8,04	
500			16,33	10,89	0,66	16,91	13,02	12,02	18,58	4,21	1,08	6,15	7,88	21,10	1,28	
600			11,20	7,11	9,73	8,70	12,92	-5,30	17,16	-5,26	0,44	2,49	3,39	6,03	0,82	
700			4,73	-2,82	-2,18	12,73	15,74	-6,04	5,77	0,14	-1,08	1,17	3,05	-0,52	0,56	
800			-7,59	15,47	0,02	5,57	7,48	2,70	5,75	-4,21	-1,37	-0,28	-4,21	-2,56	-1,59	
900			-14,61	13,60	3,69	7,83	4,43	7,51	1,88	0,84	0,22	0,04	1,98	1,01	-3,35	
1000					12,73	6,24	9,23	4,67	1,20	-1,04	-1,75	-1,08	-2,14	-6,05	-5,55	
1100					8,72	7,11	-4,56	1,41	-0,11	1,36	-0,42	1,69	-3,79	-8,99	-8,18	
1200					-3,80	0,85	1,37	3,19	-0,08	2,69	-2,63	1,18	2,04	-6,92	-2,75	
1300					-16,12	12,61	9,15	4,75	7,01	6,41	2,89	0,49	-2,27	-3,70	-5,63	
1400					-12,20	7,67	10,65	1,71	3,45	9,53	3,61	1,94	2,50	-5,02	-4,26	
1500					9,83	14,24	10,30	7,75	4,66	5,06	4,79	3,33	-0,25	-5,56	-1,44	
1600						-7,34	9,90	-0,10	-4,14	1,92	5,36	1,55	-0,95	-0,97	-0,99	
1700						4,25	7,73	6,54	-6,56	-0,07	3,96	-0,43	1,84	-1,20	-21,60	
1800						4,39	1,26	-1,19	7,45	1,10	3,47	1,44	0,23	-0,09	-14,73	
1900						-4,94	-12,67	15,98	5,90	1,44	1,57	1,19	-0,42	-4,76	-10,39	
2000							7,73	6,34	7,48	4,23	0,72	-0,78	-3,25	-2,53	-9,77	
2100								8,91	8,70	5,90	5,08	-3,03	-3,22	-9,93		
2200								3,02	7,15	7,52	6,85	-2,60	-3,72	-15,91		
2300								14,02	4,19	1,52	2,67	-0,34	-4,74	-13,73		
2400								-10,02	1,78	-0,47	2,65	-4,40	-8,22	-20,04		
2500								5,30	-3,82	0,67	-4,33	-1,39	-3,27			
2600								5,06	-2,29	0,99	-2,12	-8,29				
2700								-1,29	0,26	-7,77	-7,40					
2800								-6,10	-6,79							
2900																
3000																

=> maps for $\dot{Q}_{coolant}$, $\dot{m}_{charge\ air}$, $p_{charge\ air}$, $t_{charge\ air}$,

Cooling system optimization for TIV

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Transient simulation model



Cooling system optimization for TIV

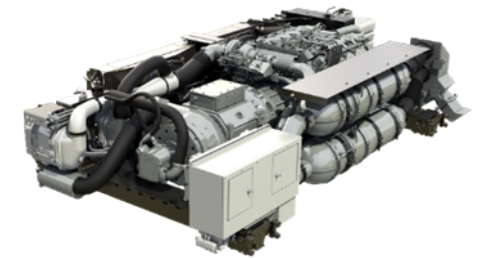
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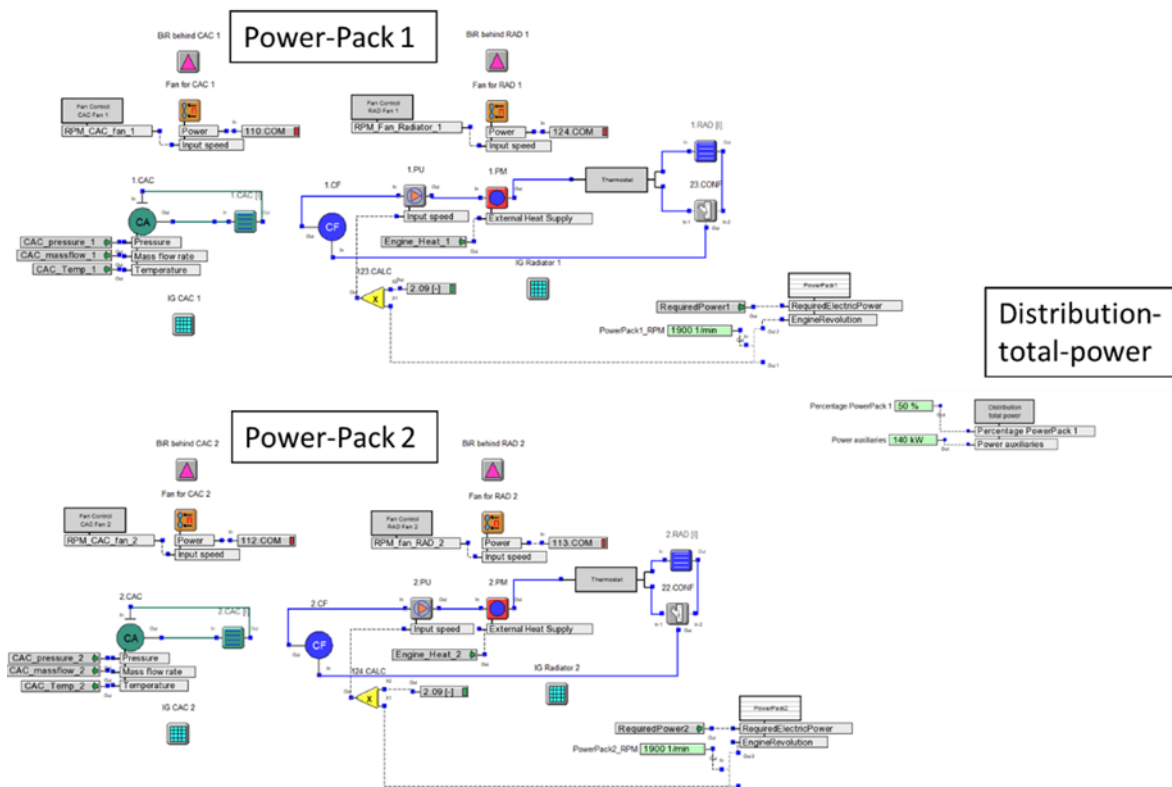


Cooling system optimization for TIV

Steady state simulation model

Plasser & Theurer

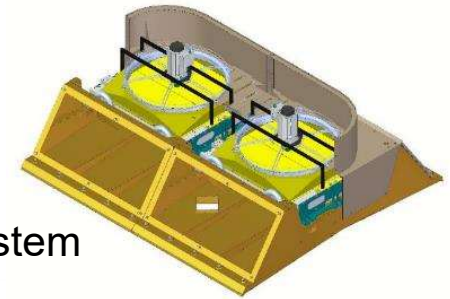
Power pack cooling system



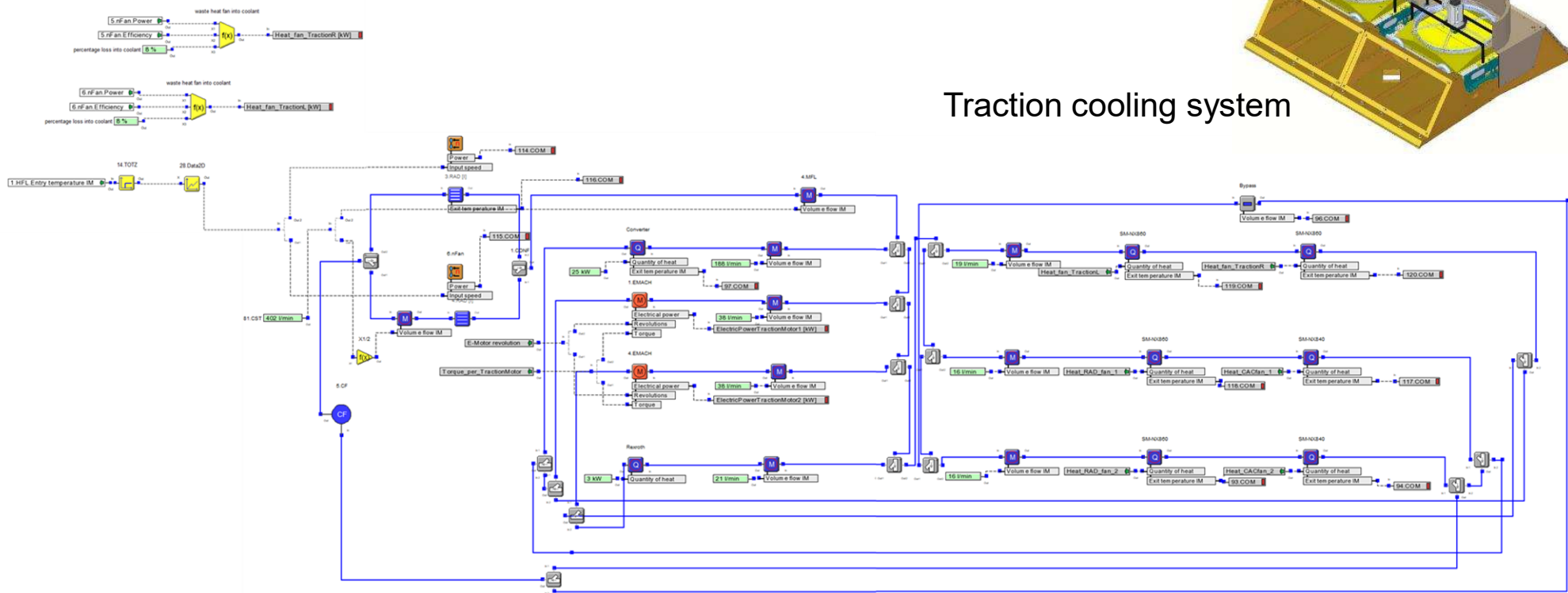
Cooling system optimization for TIV

Steady state simulation model

Plasser & Theurer



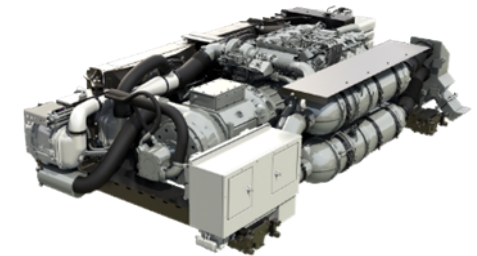
Traction cooling system



Cooling system optimization for TIV

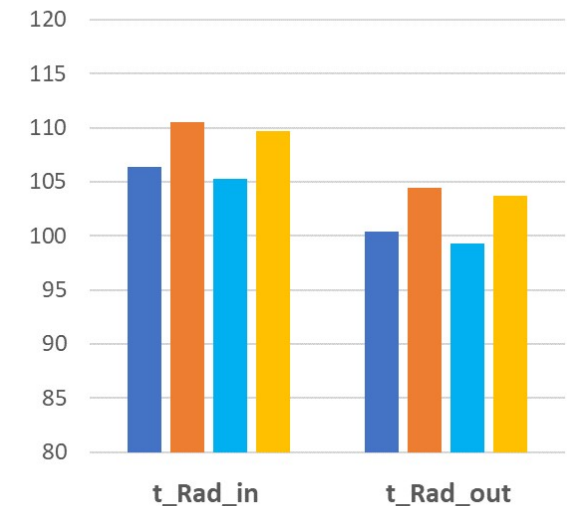
Results steady state simulation – Radiator

Plasser & Theurer



Power pack cooling System		Var. 1	Var. 2	Var. 3	Var. 4
Ambient temp.	°C	55	55	55	55
Radiator H/W/D	mm/mm/mm	1200/792/160	1200/792/160	1200/792/160	1200/792/160
glycol volume fraction	%	50	50	50	50
Fan type	-	A	A	B	B
Fan diameter	mm	710	710	850	850
Fan speed	1/min	2000	2000	1550	1550
engine speed	1/min	2100	2100	2100	2100
water pump speed	1/min	4389	4389	4389	4389
coolant flow rate	l/min	580	580	580	580
coolant spec. heat capacity @ 90°C	kJ/kg/K	3,62	3,62	3,62	3,62
coolant density @ 90°C	kg/dm³	1,027	1,027	1,027	1,027
coolant mass flow @ 90°C	kg/s	9,93	9,93	9,93	9,93
coolant circuit heat	kW	216	216	216	216
Fouling factor Radiator	%	0	20	0	20
coolant temp. Radiator in	°C	106,37	110,48	105,26	109,67
coolant temp. Radiator out	°C	100,37	104,48	99,26	103,67
Δt Radiator	°K	6,0	6,0	6,0	6,0

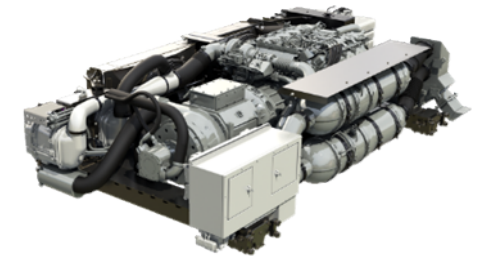
Remark : Built in resistance (BIR) for Radiator and CAC according to low Truck30 application !



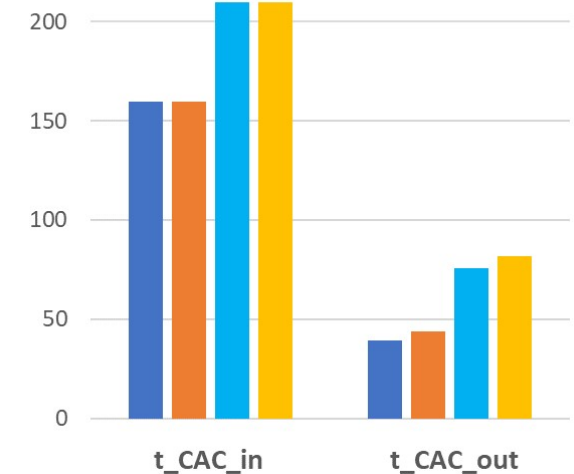
Cooling system optimization for TIV

Results steady state simulation – Charge air cooler

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Power pack cooling System		Var. 1	Var. 2	Var. 3	Var. 4
ambient temperature	°C	25	25	55	55
charge air cooler (CAC)	mm/mm/mm	792/750/160	792/750/160	792/750/160	792/750/160
engine load	%	100	100	100	100
fan type	-	C	C	C	C
fan diameter	mm	706	706	706	706
fan speed	1/min	1650	1650	1650	1650
engine speed	1/min	2100	2100	2100	2100
charge air pressure inlet	hPa	1950	1950	1950	1950
avg. charge air spec. heat capacity	kJ/kg/K	1,019	1,019	1,019	1,019
average charge air density	kg/m³	1,765	1,765	1,765	1,765
charge air mass flow	kg/s	0,88	0,88	0,88	0,88
charge air circuit heat	kW	108,05	104,12	120,52	115,14
Fouling factor CAC	%	0	20	0	20
charge air temperature CAC in	°C	160	160	210	210
charge air temperature CAC out	°C	39,5	43,89	75,6	81,6
Δt CAC	°K	120,5	116,11	134,4	128,4
ETD	°K	14,5	18,9	20,6	26,6



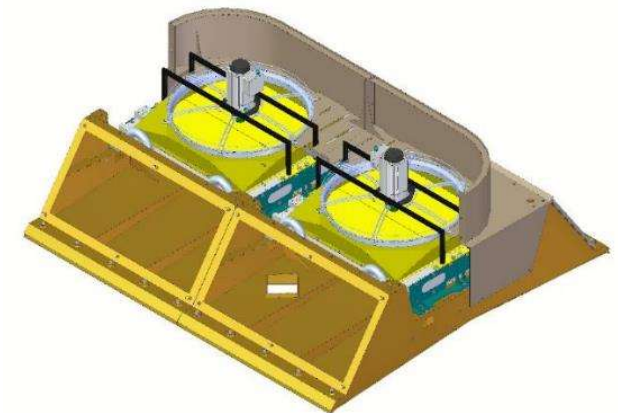
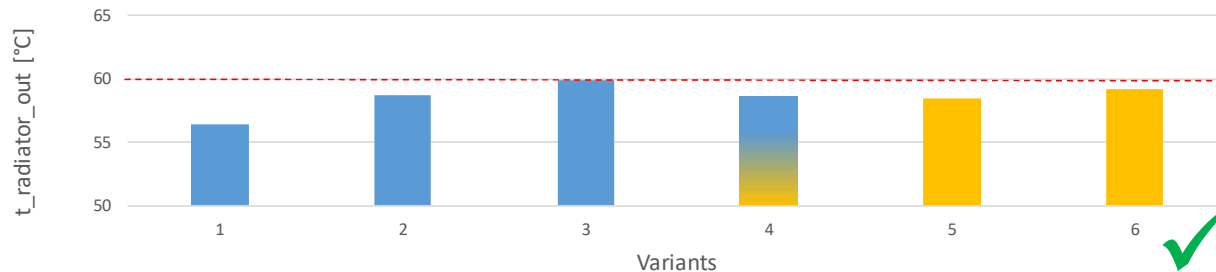
Remark : Built in resistance (BIR) for Radiator and CAC according to low Truck30 application !



Cooling system optimization for TIV

Results steady state simulation

Var.	Ambient temp.	glycol volume fraction	Rad. type	Radiator H/W/D	no. of Radiators	Fan type	Fan diameter	Fan speed	coolant flow rate	coolant circuit heat	fouling factor Radiator	t_out
	°C	%	-	mm/mm/mm	-	-	mm	1/min	l/min	kW	%	°C
1	55	50	A	1200/792/160	4	A	710	2000	360	82,5	0	56,5
2	55	50	A	1200/792/160	2	A	710	2000	360	80	0	58,7
3	55	50	A	1200/792/160	2	A	710	1550	360	80	0	60,0
4	55	50	A	1200/792/160	2	B	850	1550	360	80	0	58,6
5	55	50	B	1000/932/160	2	B	850	1550	360	80	0	58,5
6	55	50	B	1000/932/160	2	B	850	1550	360	80	10	59,2

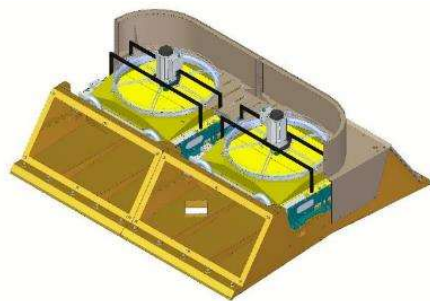


Traction cooling system

Cooling system optimization for TIV

Transient KULI simulation model

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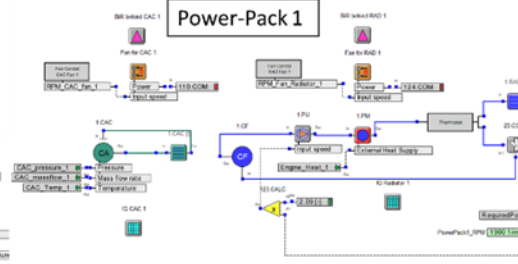


Traction cooling system

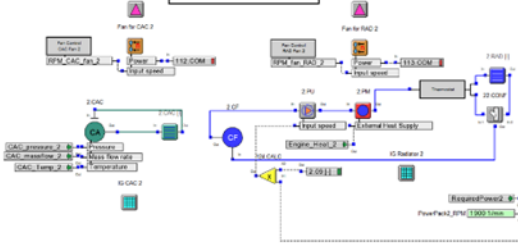
Driving-Simulation



Power-Pack 1



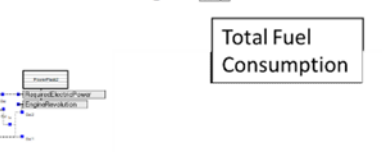
Power-Pack 2



Distribution-total-power



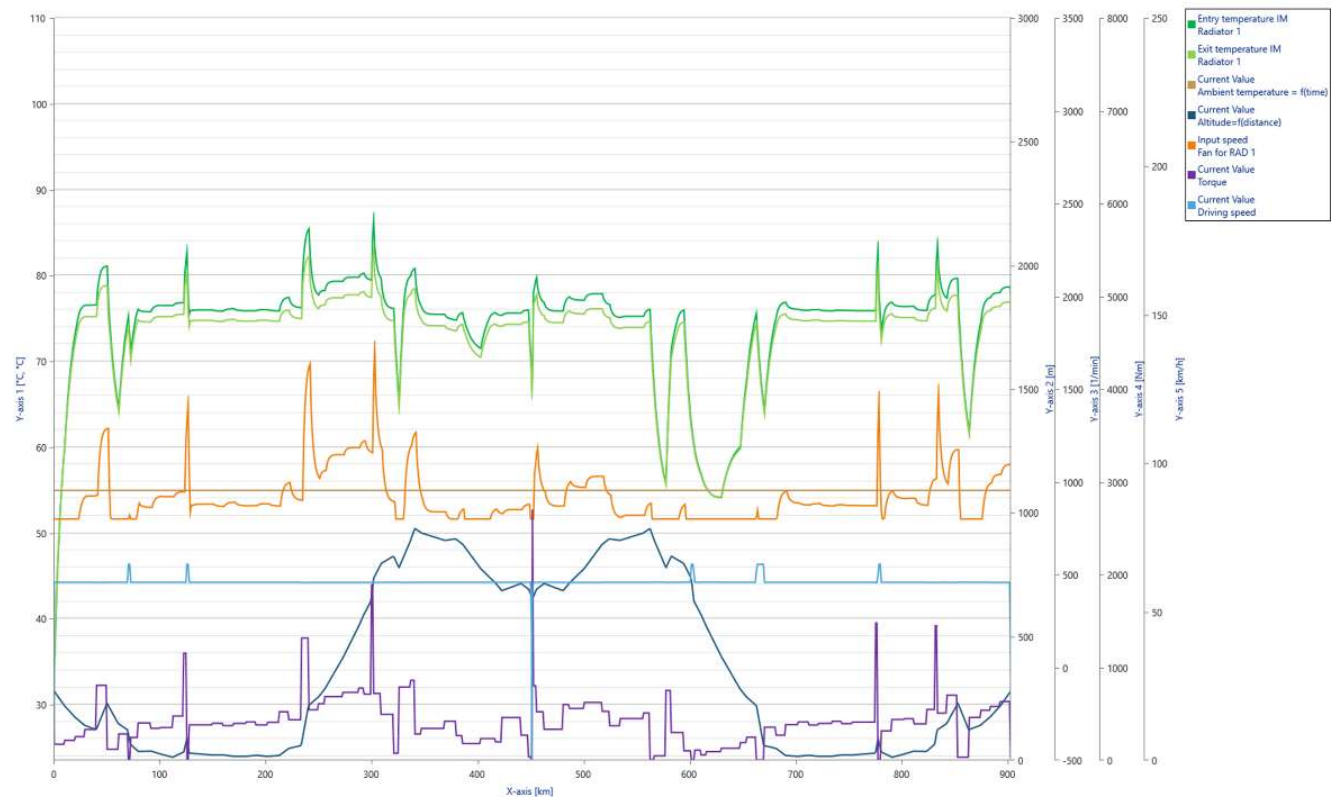
Total Fuel Consumption



Cooling system optimization for TIV

Results transient simulation

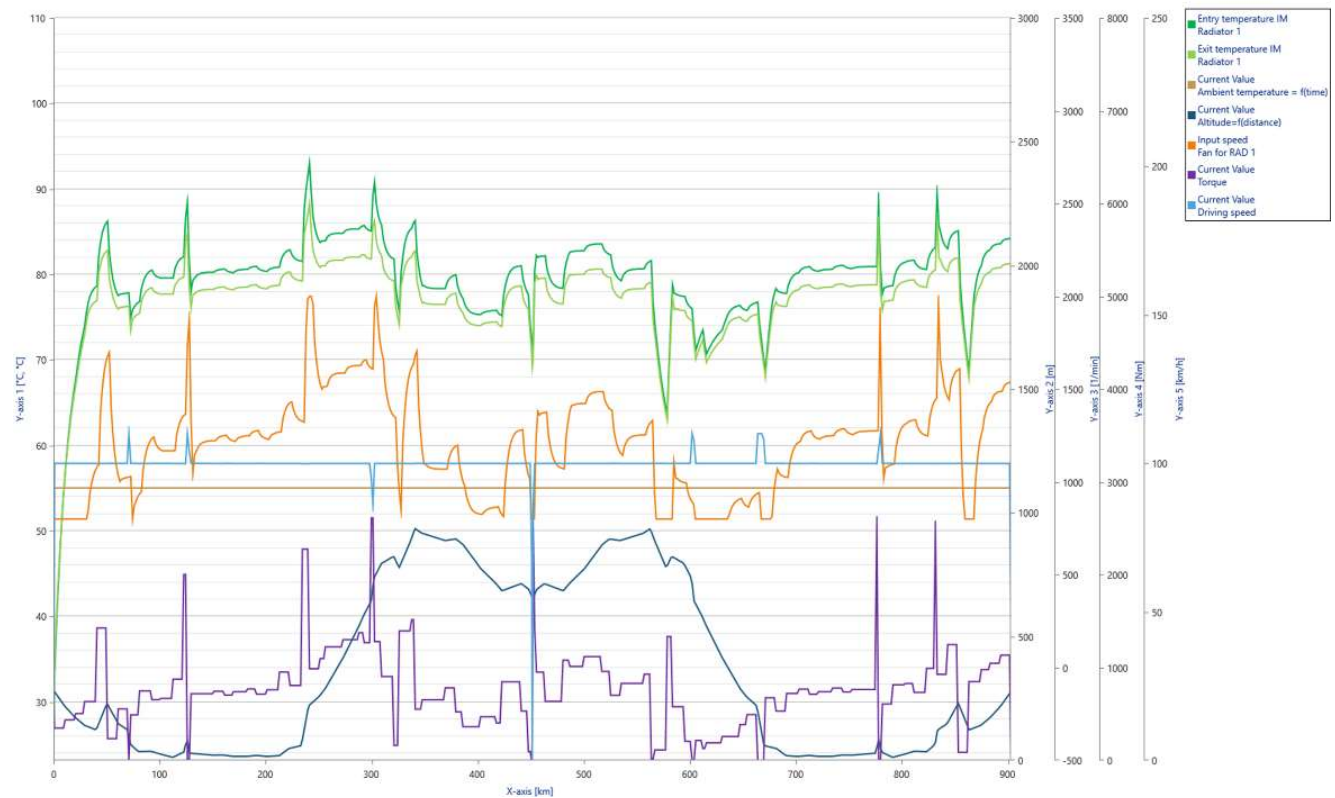
target speed = 60 km/h



Cooling system optimization for TIV

Results transient simulation

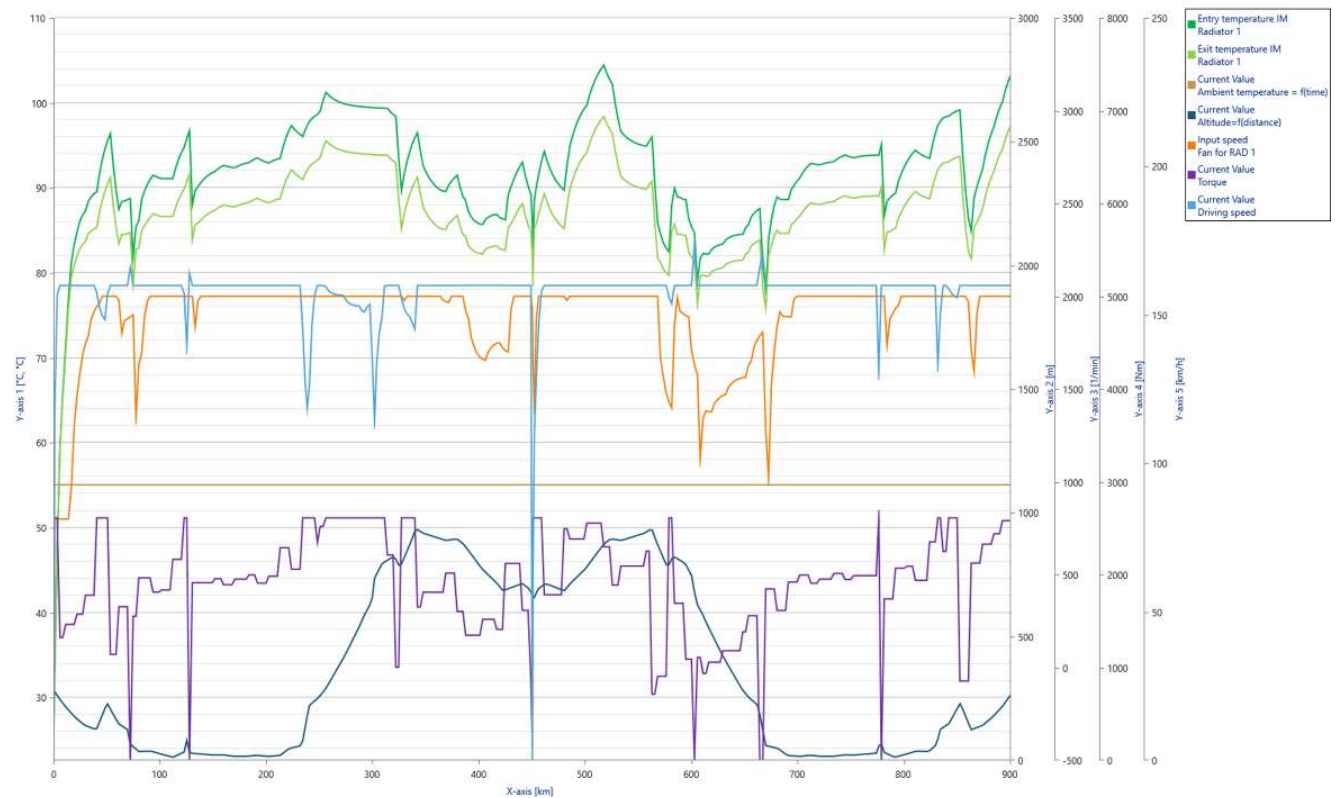
target speed = 100 km/h



Cooling system optimization for TIV

Results transient simulation

target speed = 160 km/h



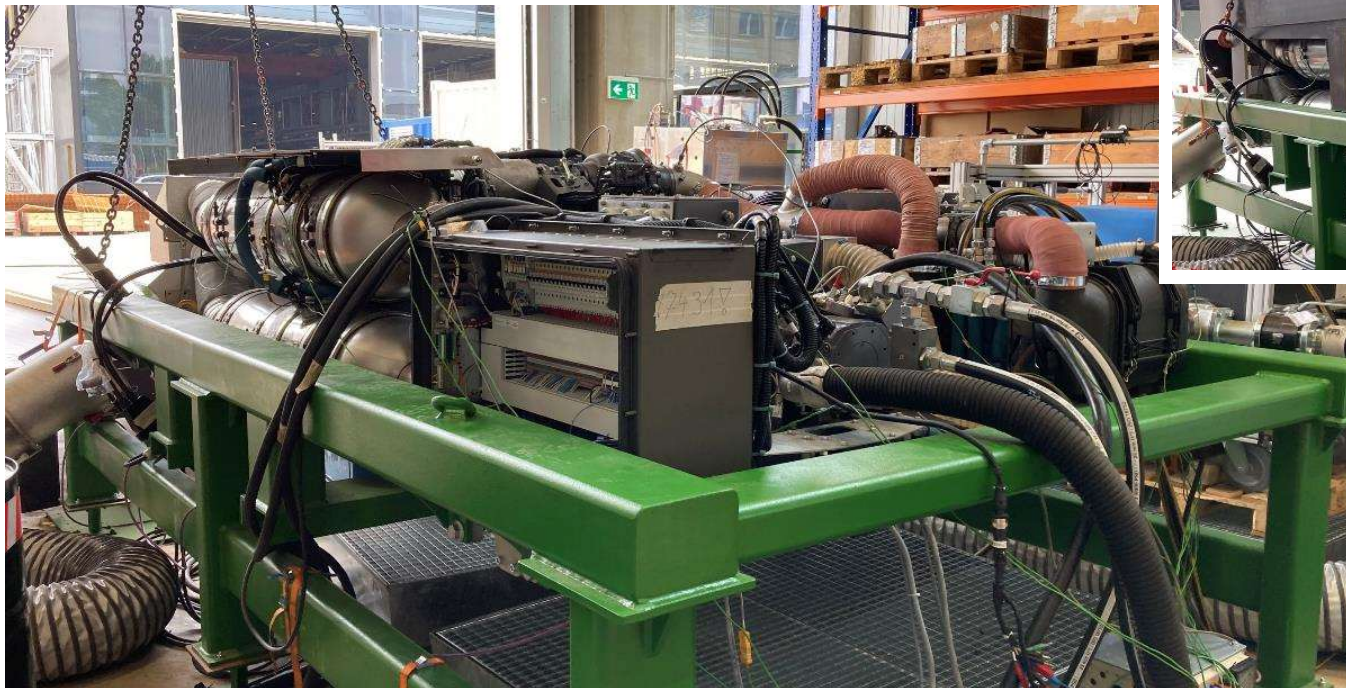
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Cooling system optimization for TIV

Summary & Outlook



Power pack test bench for system measurements and simulation model calibration is a perfect base for further optimizations !

Summary & Outlook

Summary: "What did we already achieve ?"

- Reduction of system complexity and costs ✓
- Component optimization and parameter definition for the controllers ✓
- Functional guarantee for extreme use conditions ✓
- Impact analysis of heat exchanger fouling ✓

Outlook: "What are the next steps ?"

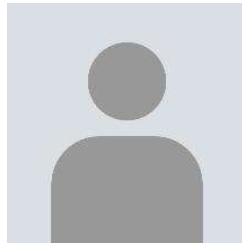
- Further development of system controllers based on component maps ☐
- Optimization of the dynamic vehicle power train model ☐
- Reduction of the fuel consumption => CO₂-reduction potential ☐
- Intelligent vehicle and component control ☐



KULI - a great tool to work with !

Many thanks for your attention !





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