

Heavy duty cooling system analysis for commercial vehicles



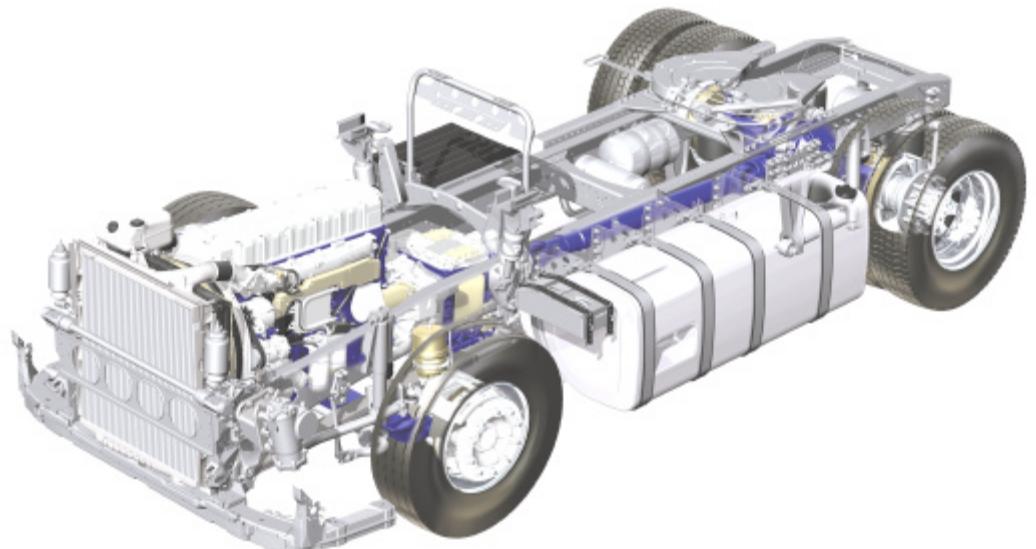
5th International KULI User Meeting
29th – 30th of June 2005, Steyr Austria

Dolf van der Maarel, Volvo Truck Corporation

Heavy duty cooling system analysis for commercial vehicles

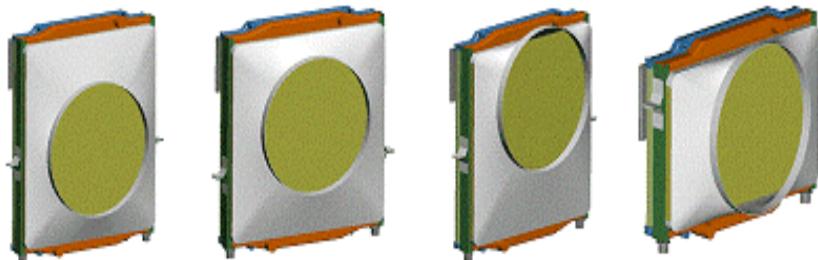
Content:

- Introduction
- Driving parameters & challenges
- Air flow implementation
- Examples
- Questions & answers



Integrated engineering approach

Design:

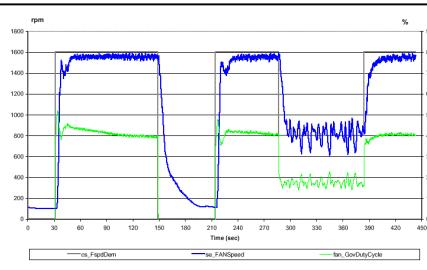


Test & Analysis:

Vehicle testing



Function testing

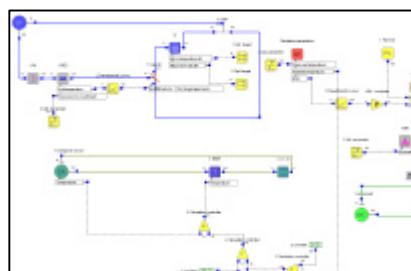


Component testing

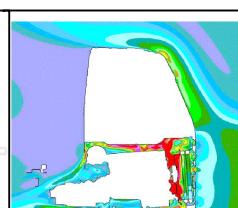


Simulation and analysis tools:

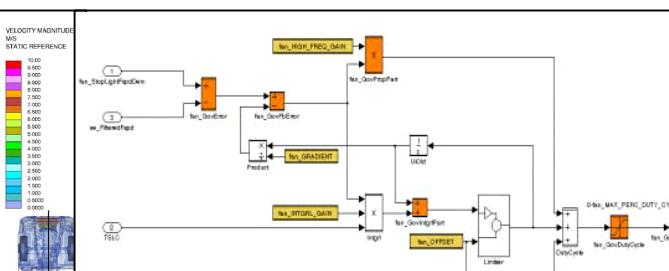
KULI



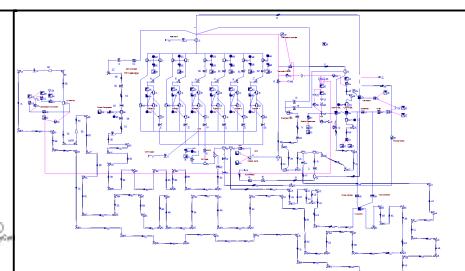
StarCD



Matlab Simulink



Flowmaster



Simulation application areas

Early development phase:

Concept studies

Evaluate proposals of different suppliers

Midterm development phase:

Find the best test configurations

Fine-tune simulation model: BIR, flow restrictions, Cp

Parameter variation:

- fan ratio / fan type / fan diameter
- fin density / geometry

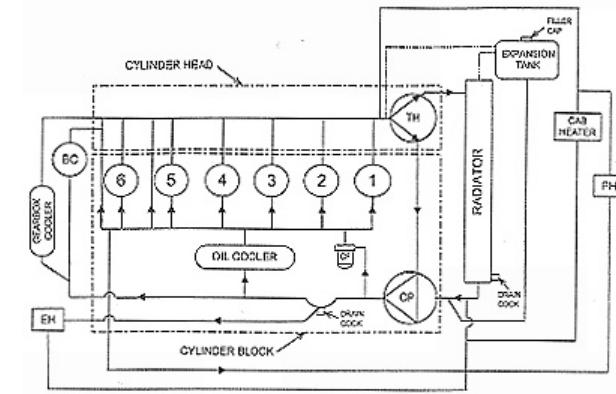
Validation phase:

Simulate final concept with proposed engine ratings

Validate cooling system performance demands

Product modification tests

Drivecycle simulation

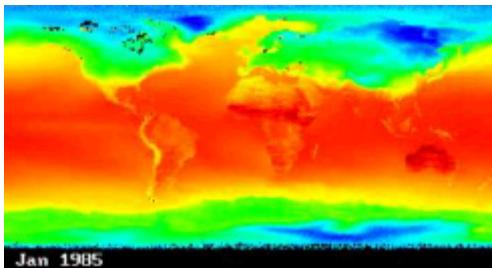


BC = Brake Compressor
CF = Coolant Filter (oilline)
CP = Coolant Pump
TH = Thermostat Housing
PH = Parking Heater (extra equipment)
EH = Extra Heater (Aurora heater)
— = Operation lines



Driving parameters cooling system design

Climate



Topography



Road conditions



Application



Challenges cooling system development

Demand for higher engine ratings

→ Heat rejection ↑

Legislative demands

→ Exhaust emission → Heat rejection

Noise emission

→ Fan speed restriction

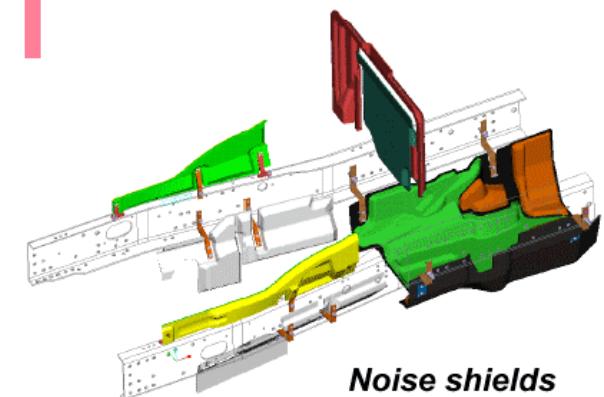
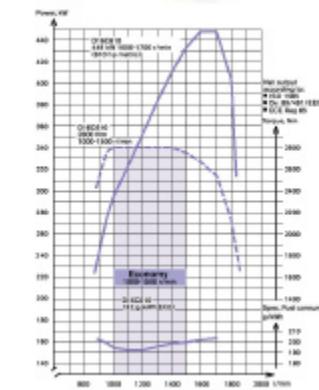
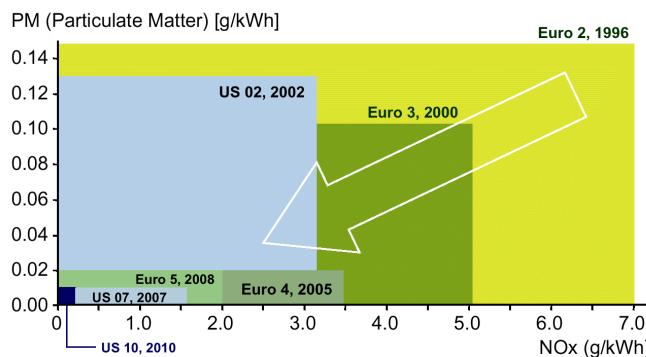
Noise shields → airflow restriction

Conflicting coolant temperature demands

→ Thermal management more complex

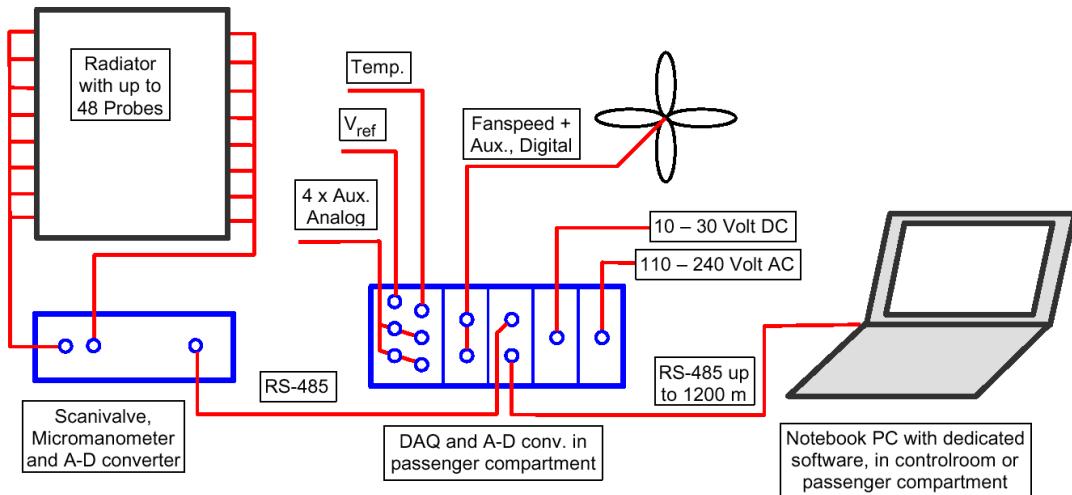
No. components needing cooling increasing

→ Heat rejection ↑



Cooling air flow measurement

The MicroProbe System Set-up:



MicroProbe



MicroProbes glued in HTX



Calibration



Cooling air flow measurement

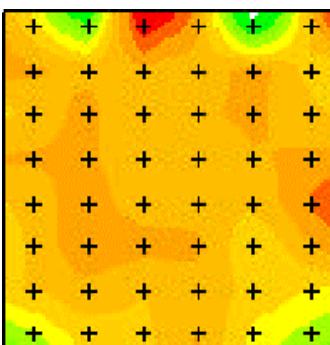
In vehicle testing



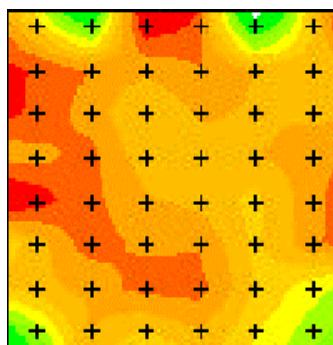
KULI Advanced

Cooling air flow

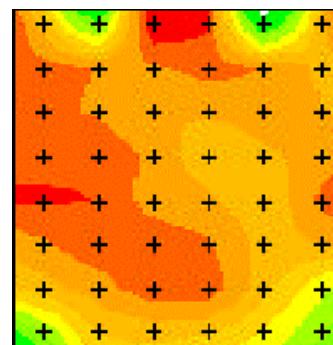
790 rpm



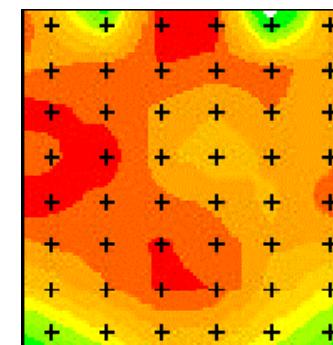
1080 rpm



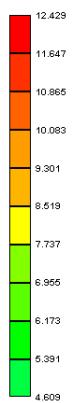
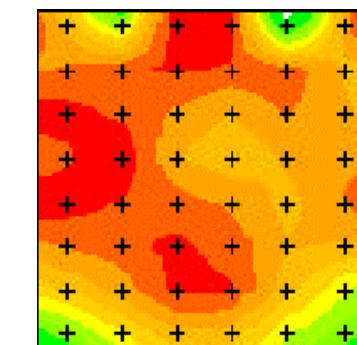
1330 rpm



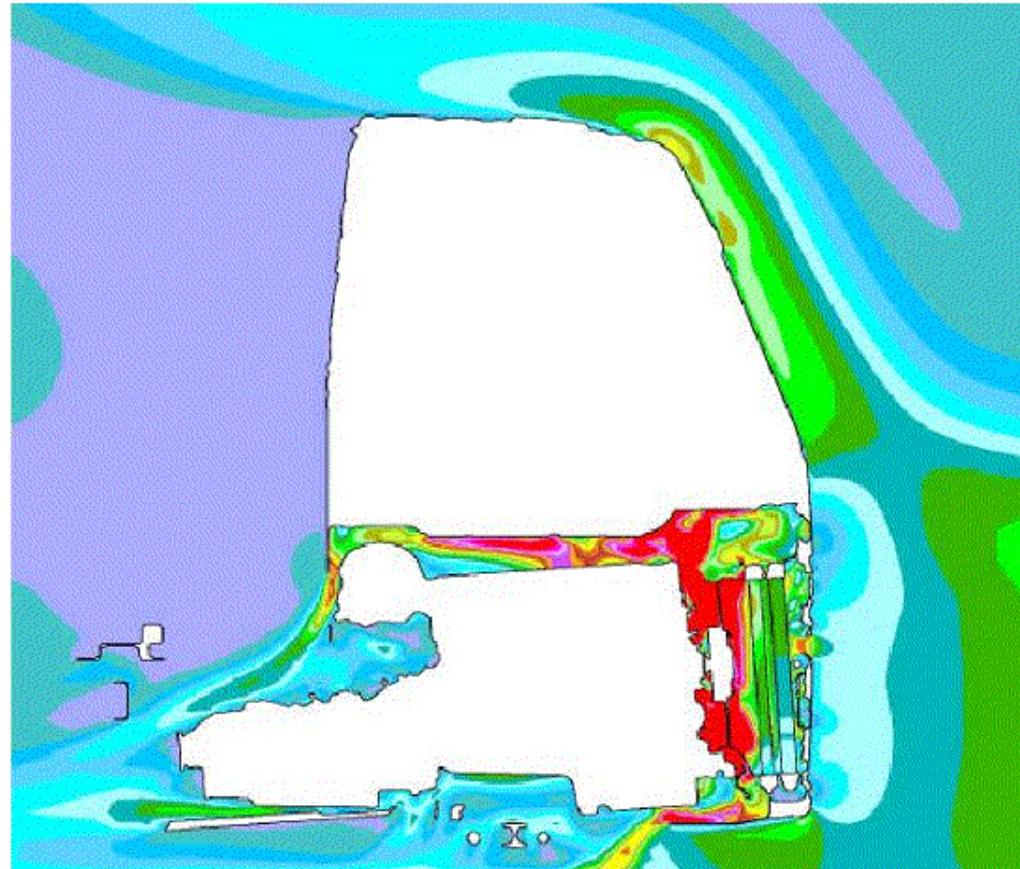
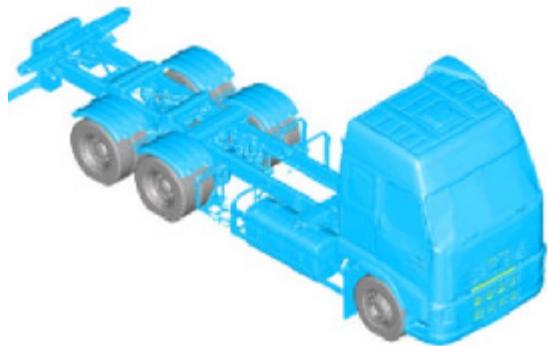
2050 rpm



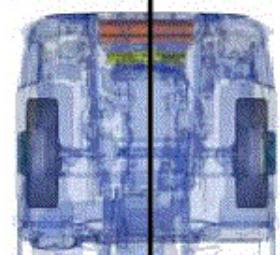
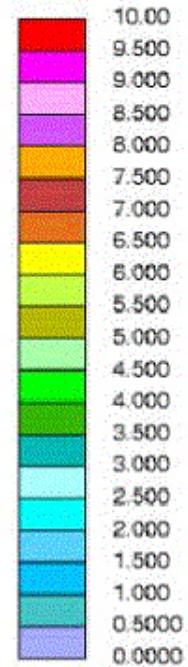
2770 rpm



CFD air flow analysis

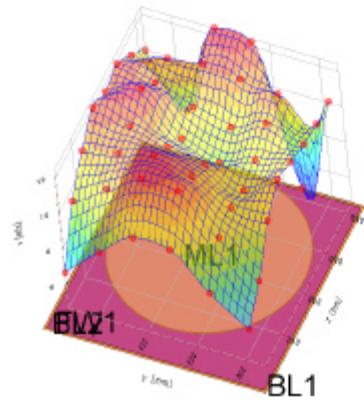


VELOCITY MAGNITUDE
M/S
STATIC REFERENCE



Implementing data in KULI

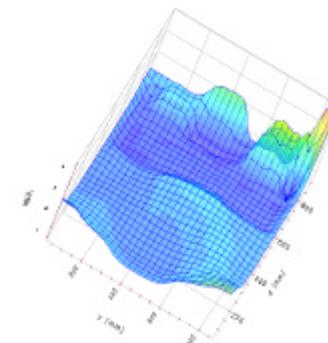
CFD velocity field



Legend

11.941 : 12.429
11.452 : 11.941
10.963 : 11.452
10.474 : 10.963
9.9856 : 10.474
9.4969 : 9.9856
9.0081 : 9.4969
8.5193 : 9.0081
8.0305 : 8.5193
7.5417 : 8.0305
7.053 : 7.5417
6.5642 : 7.053
6.0754 : 6.5642
5.5866 : 6.0754
5.0979 : 5.5866
4.6091 : 5.0979

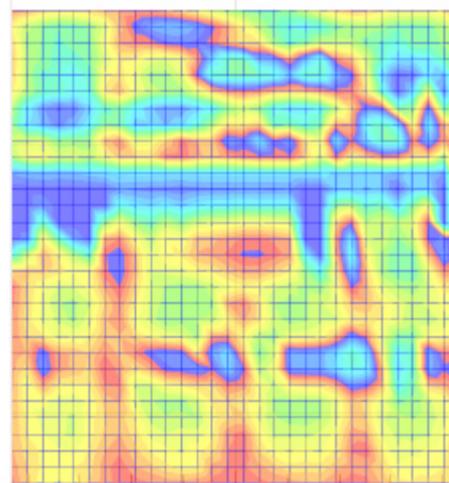
Loss coeff.



Legend

3.8144 : 4.0409
3.5878 : 3.8144
3.3612 : 3.5878
3.1347 : 3.3612
2.9081 : 3.1347
2.6816 : 2.9081
2.455 : 2.6816
2.2284 : 2.455
2.0019 : 2.2284
1.7753 : 2.0019
1.5488 : 1.7753
1.3222 : 1.5488
1.0957 : 1.3222
0.86909 : 1.0957

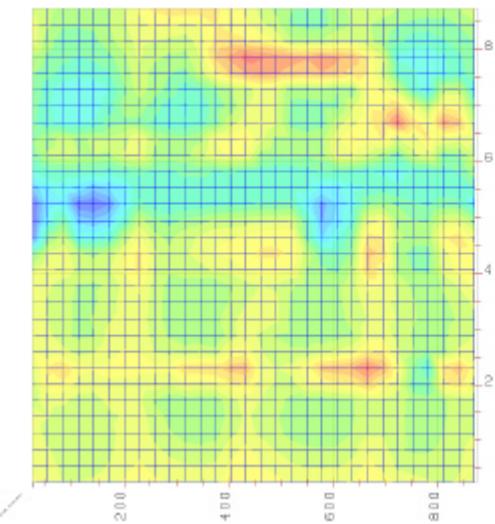
Static pressure



Legend

100300 : 100300
100300 : 100300
100300 : 100300
100300 : 100300
100290 : 100300
100290 : 100290
100290 : 100290
100290 : 100290
100280 : 100290
100280 : 100280
100280 : 100280
100280 : 100280
100280 : 100280
100270 : 100280
100270 : 100270

CP value



Legend

0.98798 : 1
0.97597 : 0.98798
0.96396 : 0.97597
0.95193 : 0.96395
0.93992 : 0.95193
0.9279 : 0.93992
0.91588 : 0.9279
0.90387 : 0.91588
0.89185 : 0.90387
0.87984 : 0.89185
0.86782 : 0.87984
0.8558 : 0.86782
0.84379 : 0.8558
0.83177 : 0.84379
0.81975 : 0.83177
0.80774 : 0.81975

KULI Advanced needed

Simulation parameters

PERF Windows Version

File Calculations View Settings ?

Customer: FH12 **Id:** FH16-610-V1

Engine: D16C610	GCW / GVW: 60 ton				
Gearbox: VT02814B	Driving axle(s) pressure: 13 ton				
Rear Axle: RS1370HV	Frontal Area: 9.7 m ²				
Rear Axle Ratio: 3.61	Air Resistance: 0.53				
Tyres: 315/80R22.5	Rolling Resistance: 50 N/ton				
Rolling Radius: 0.522 m	Coeff of Friction: 0.8				
No of Wheels: 12	Application: Combination				
<input type="checkbox"/> With indexed fuel consumption					
ROADSIM					
Calculate					
Spec	Alt1	Alt2	Alt3	Alt4	Alt5

Ready

Performance Summary

File Options ?

Customer: FH12 **Id:** FH16-610-V1 **Status:**

Results		Spec	
 Economy Speed Range: 1000-1600 rpm Speed Range top gear: 60.1-109 km/h Max Nominal Speed: 122.7 km/h Grade Speed: 3.0 % 62.7 km/h (5L) 8.0 % 25.8 km/h (3L)		D16C610 VT02814B RS1370HV 3.61 315/80R22.5 0.522 m 12 60 ton 13 ton 9.7 m ² 0.53 50 N/ton 0.8 90 km/h	
Max Gradeability:	1.6 % (6H)	At	68.1 km/h (1000 rpm)
	2.3 % (6L)	At	54.5 km/h (1000 rpm)
Gradeability:	1.5 %	At	90.0 km/h (1321 rpm)
Startability:	12.9 % (DL)		1.0 %
	11.1 % (1L)		8.0 %

Ready

Drivecycle data acquisition

Roads 016
Target speeds : 80
Percent 100
Wind speed 4 m/s **Schwung** 10 km/h
Driving strat : Economy
Min, downshift, upshift rpms used: 1100, 1150, 1600.

Results:

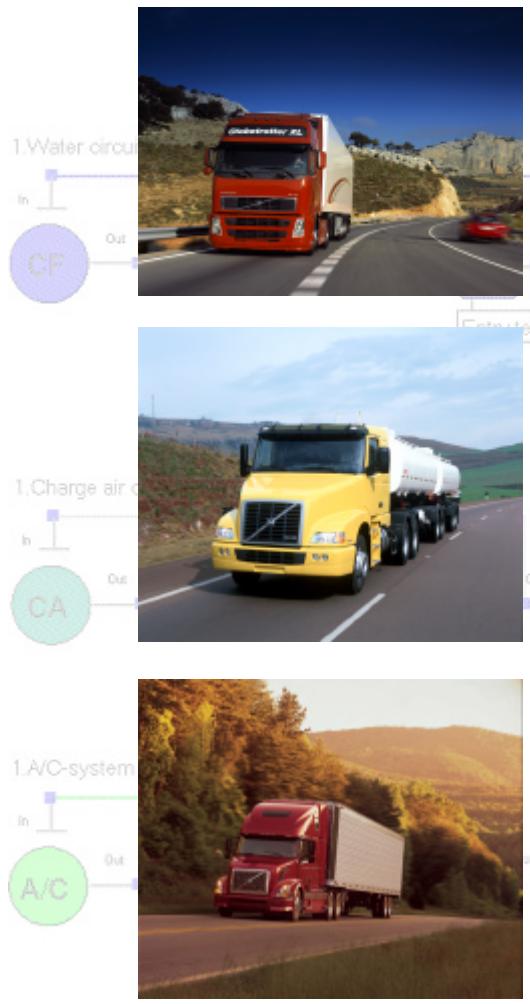
Roadno, name 16 Motorway, southern Sweden
Distance 61.6 km **Time** 8 h
Fuel cons 45.8 l/100km **Average speed** ... 80.1 km/h
 6.17 UK MPG
Fuel total 28.2 l **Max speed** 90 km/h
Gearshifts 455 /km **Baseshifts** 11 /km
Downshifts 146 /km **Rangeshifts** 02 /km
Upshifts 308 /km **Splitshifts** 34 /km

Net average output, Engine : 147.4 kW (200.5 hp)

Net average torque, Engine : 1693.6 Nm

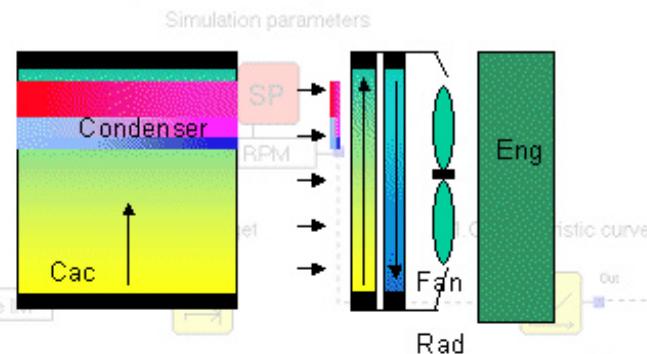
Gear.....	CL	CH	1L	1H	2L	2H	3L	3H
Ratio.....	12.96	10.34	8.79	7.02	5.65	4.51	3.75	2.99
km/h.....	7.6	9.5	11.2	14	17.4	21.8	26.2	32.8
% of road:	0	0	0	0	0	0	.1	.1
Gear.....	4L	4H	5L	5H	6L	6H		
Ratio.....	2.34	1.87	1.51	1.2	1	.8		
km/h.....	41.9	52.5	65	81.8	98.1	122.7		
% of road:	.1	.2	.4	1	17.5	80.2		

FH / NH / VN

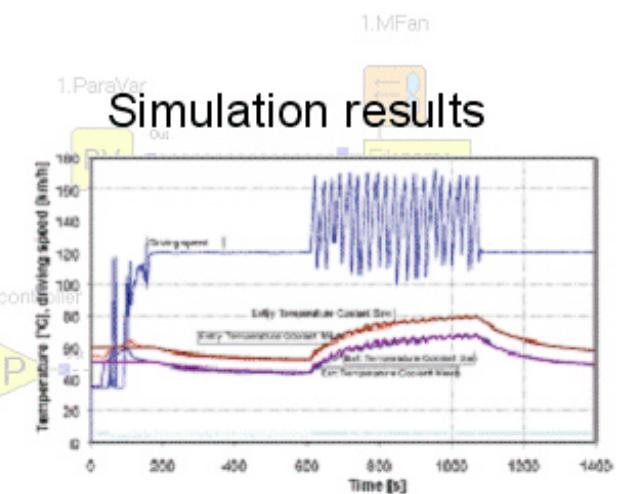
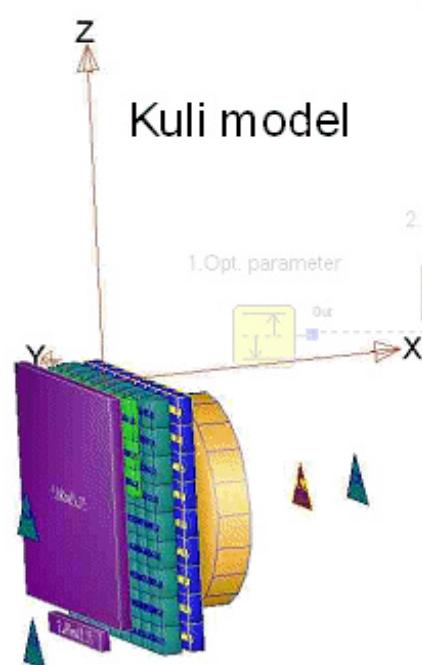


KULI Analysis

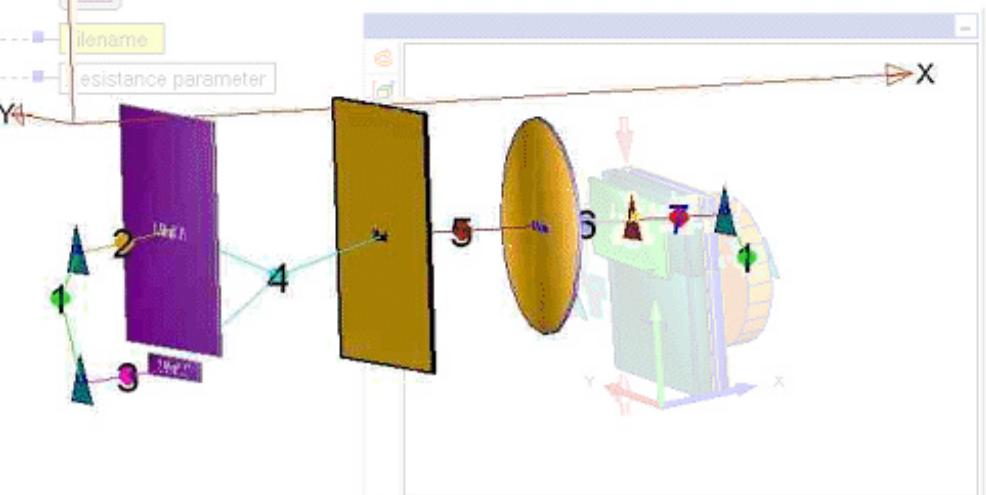
System layout



Kuli model

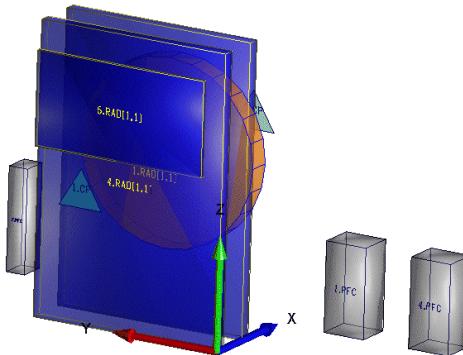


External flow model



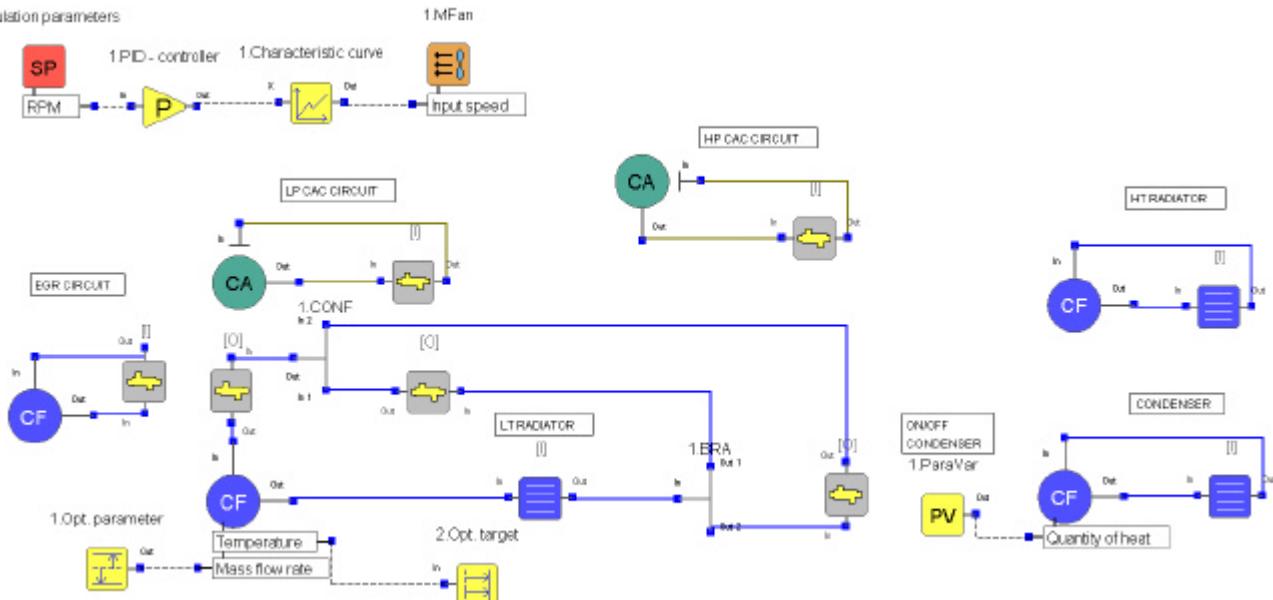
Cooling concept evaluation

Cooling module layout

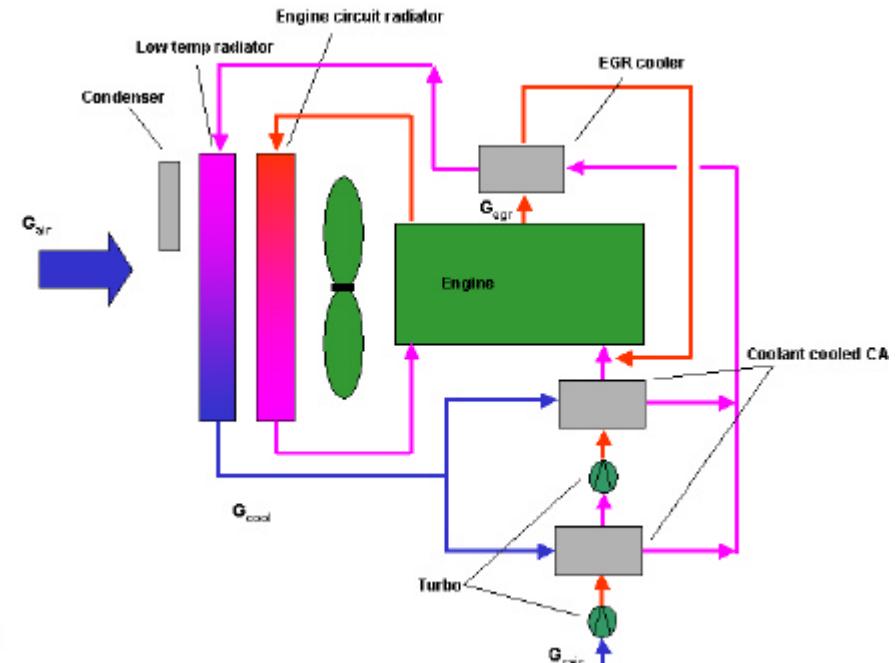


Inner circuit

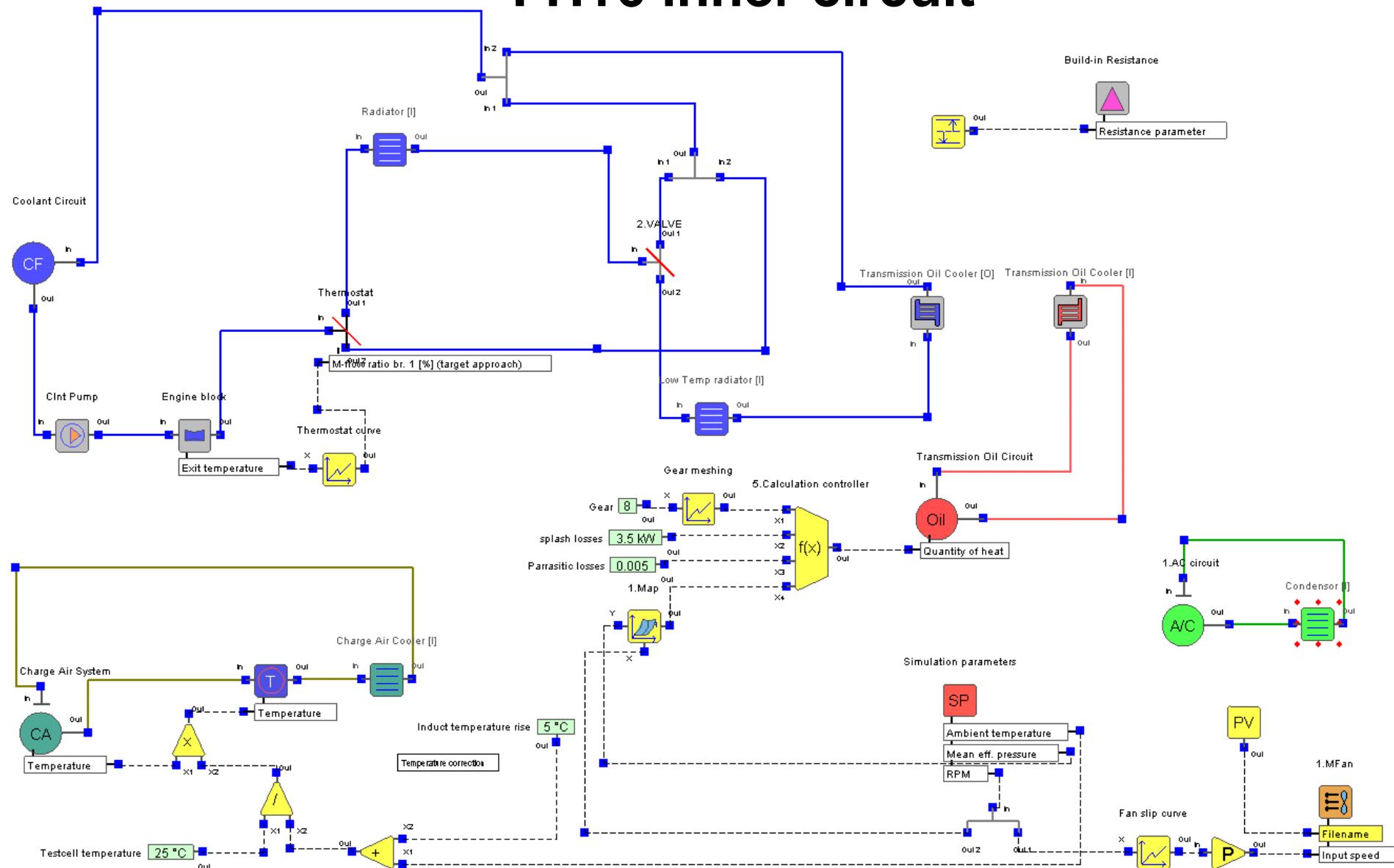
Simulation parameters



Principle flow schematic



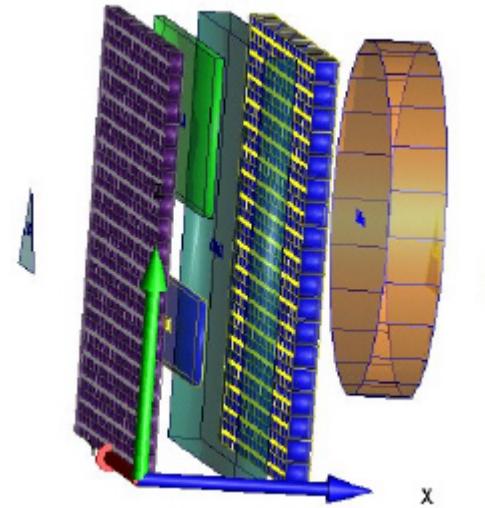
FH16 inner circuit



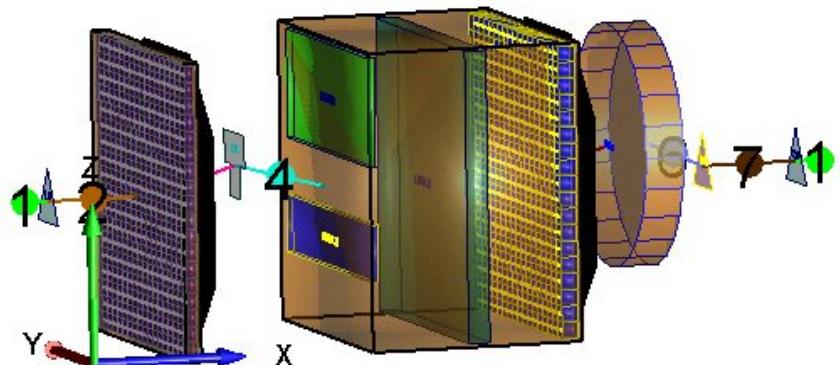
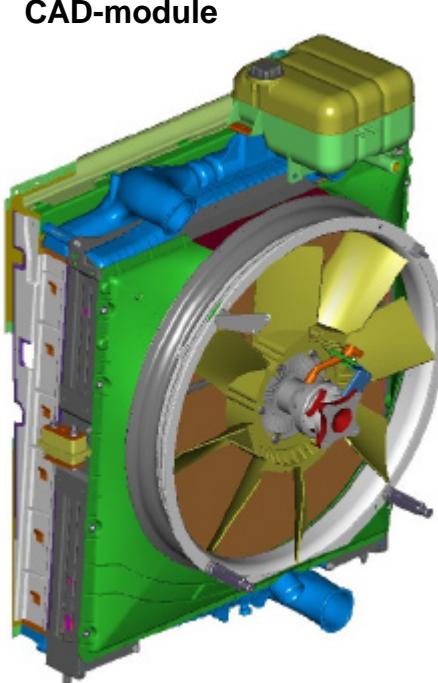
FH16 KULI model



Cooling module layout



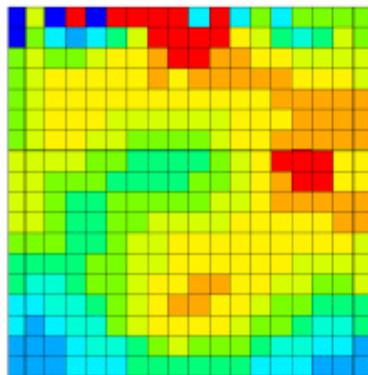
Air flow path / Air side



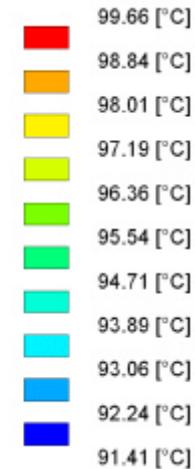
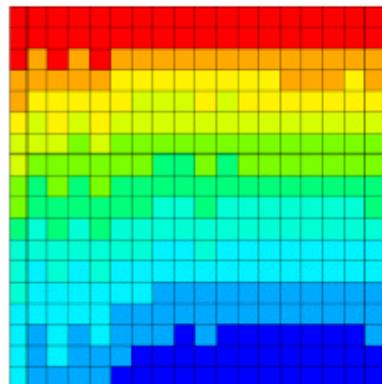
Kuli analysis results

Diagrams

Entry speed CAC



Coolant temperature

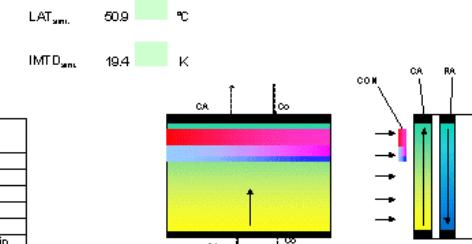


Postprocessor interface to Excel

VOLVO TRUCKS

W/G=40/60% vol. ram air = 35 km/h T_{MCR} 50.9 °C

	System	W mm	H mm	D mm	Area dm ²
Condenser		814	386	21	27.4
Charge Air Cooler		888	900	68	79.9 upflow
Radiator		888	900	52	79.9 downflow
Cp-value front		0.9		70	
Cp-value back		0.0		100	
Fan		i= 141	5.63%	... 2.88% slip	



CDYN test: input data KULI

Comment	Engine speed	Cooling air			Condenser			Charge Air Cooler			Radiator			Fan			BIR	T _{load}	T _{ext}									
		G2 kg/s	T2 °C	dp2 Pa	Q _{can} kW	dp2 Pa	G1 kg/s	T1in °C	p1in kPa	T1out °C	η _{ca,c} %	dp1 kPa	IMTD K	Q _{cac} kW	G1 kg/s	T1out °C	ETD	LAT u °C	Q _{ra} kg/s	dp2 Pa	P _{vn} kW	η _{fan} %	n s-1	ρ kg/m ³	dp2 Pa	T _{ext} °C	K	
s-1																												
OP 1	18.3	504	38	47.96	8.7	-131	0.33	105	138	47.6	93.7	-9.0	98	40	477	730	318	62.7	113	628	7.9	39.1	25.1	1.02	0.139	-250	0	0.00
OP 2	217	572	38	47.70	8.6	-166	0.46	194	189	519	93	-12.4	13.9	67	557	888	441	45.1	175	817	12.3	38.7	29.5	0.98	0.142	-334	0	1.7
OP 3	250	659	38	47.60	8.5	-213	0.58	214	217	563	91.5	-17.1	18.3	94	642	920	41	41.9	197	1062	18.5	38.9	33.8	0.97	0.146	-446	0	2.4
OP 4	300	788	38	47.50	8.5	-292	0.66	220	204	574	91.4	-23.8	19.4	109	771	908	42	43.9	216	1498	30.7	38.6	39.9	0.98	0.149	-632	0	30

Simulated: 2005-05-25

Questions & Answers



Thank you for your attention!

Dolf van der Maarel

Volvo Truck Corporation

Cooling systems

Dept 26462, AB3

SE-405 08, Göteborg, Sweden

Telephone: +46-31-32 74369

Telefax: +46-31-22 62 03

E-mail: dolf.vandermaarel@volvo.com