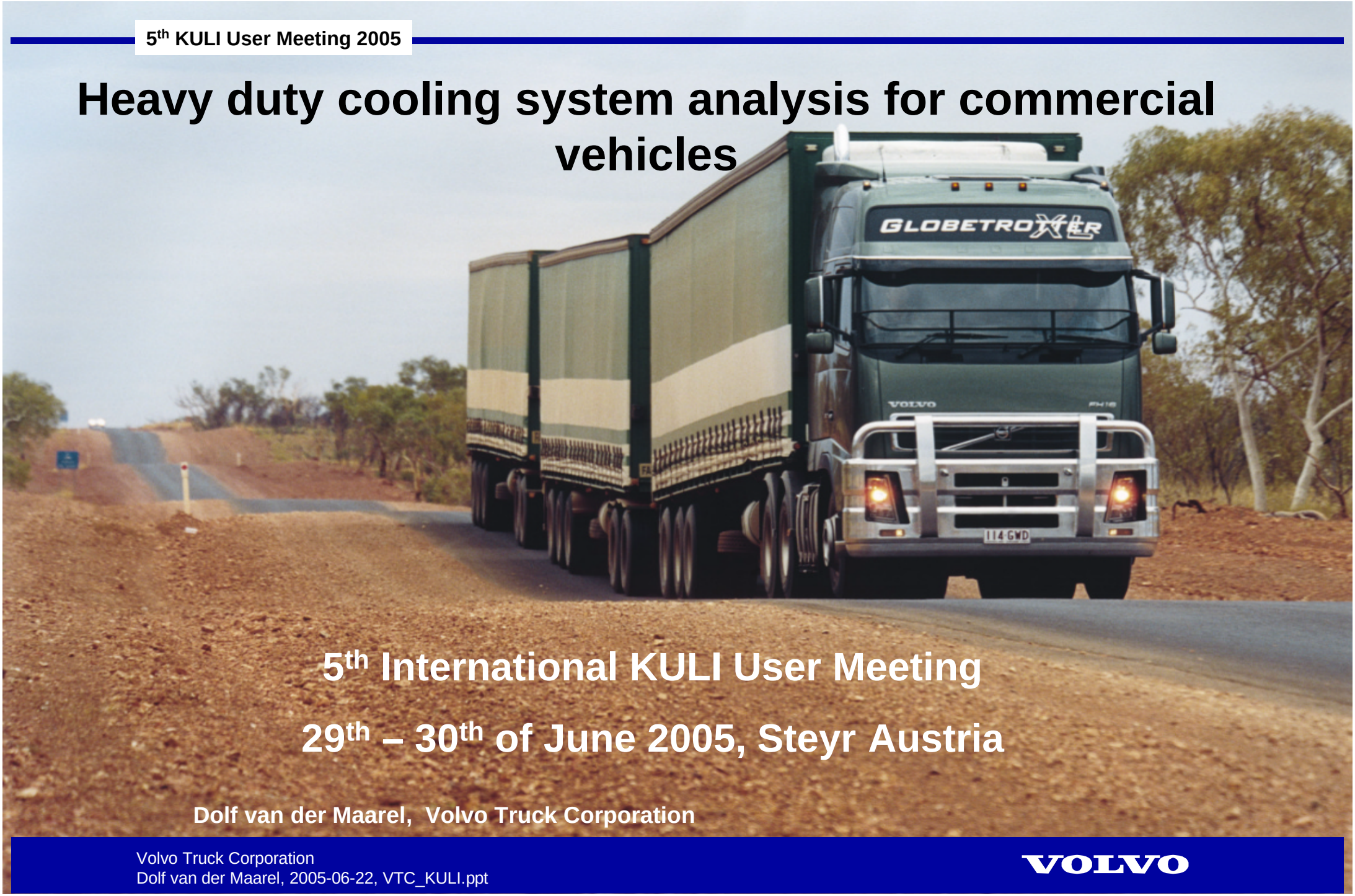
Heavy duty cooling system analysis for commercial vehicles



5th International KULI User Meeting

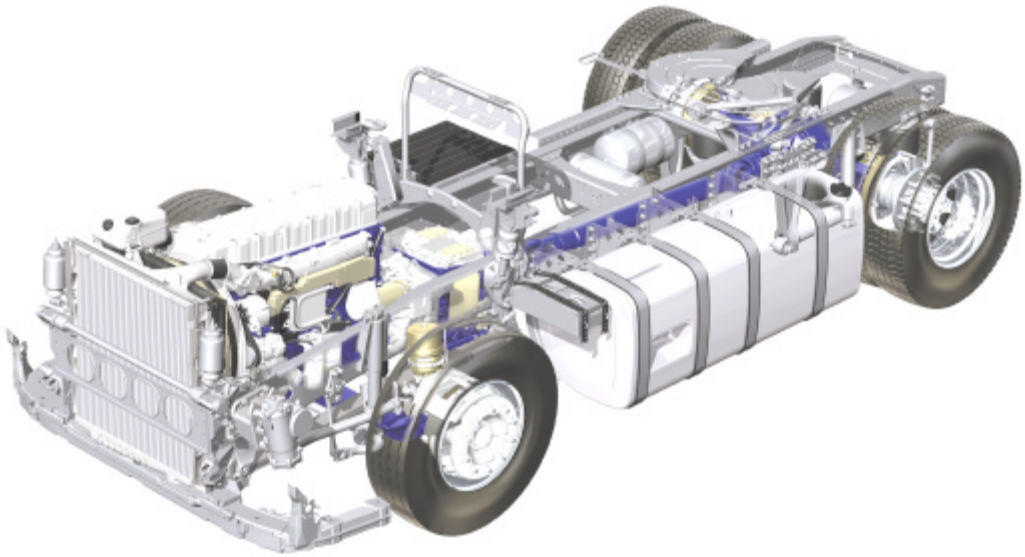
29th – 30th of June 2005, Steyr Austria

Dolf van der Maarel, Volvo Truck Corporation

Heavy duty cooling system analysis for commercial vehicles

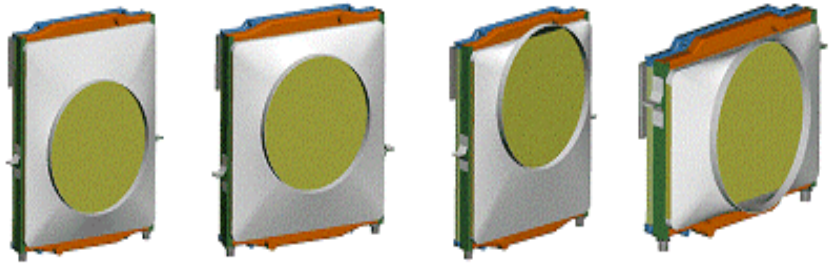
Content:

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



Integrated engineering approach

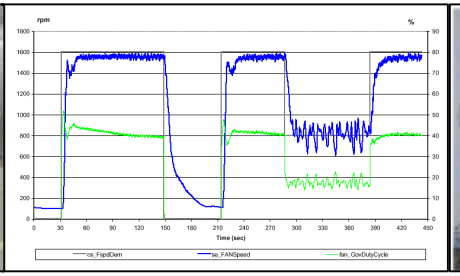
Design:



Test & Analysis:

Vehicle tesing

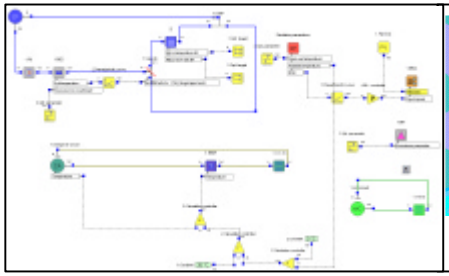
Function testing



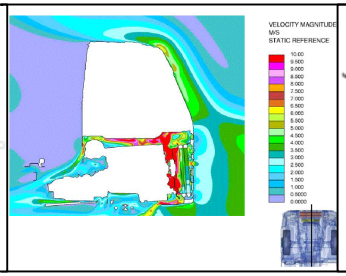
Component testing

Simulation and analysis tools:

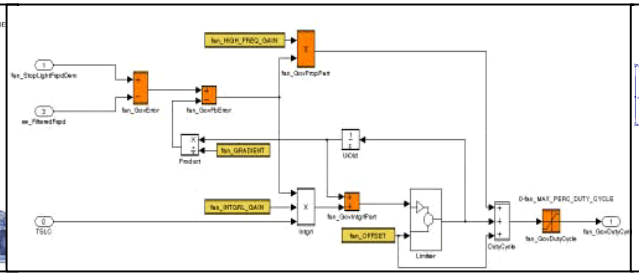
KULI



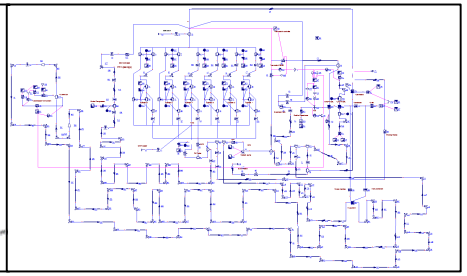
StarCD



Matlab Simulink



Flowmaster



Simulation application areas

Early development phase:

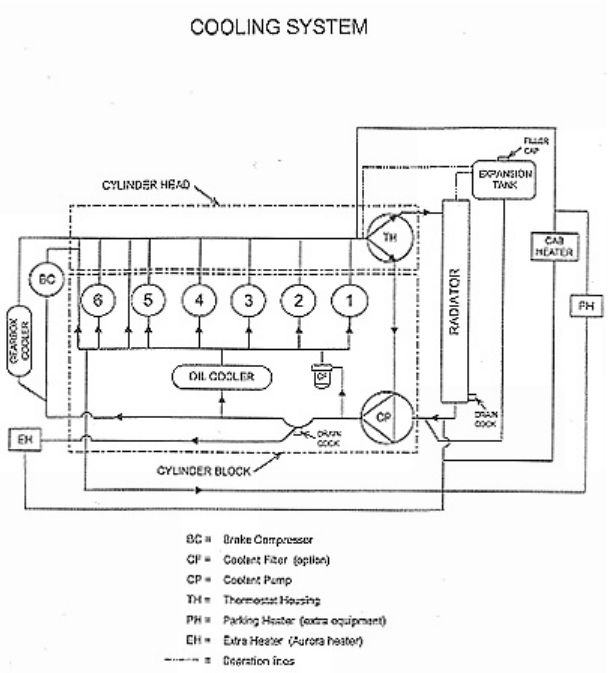
- Concept studies
- Evaluate proposals of different suppliers

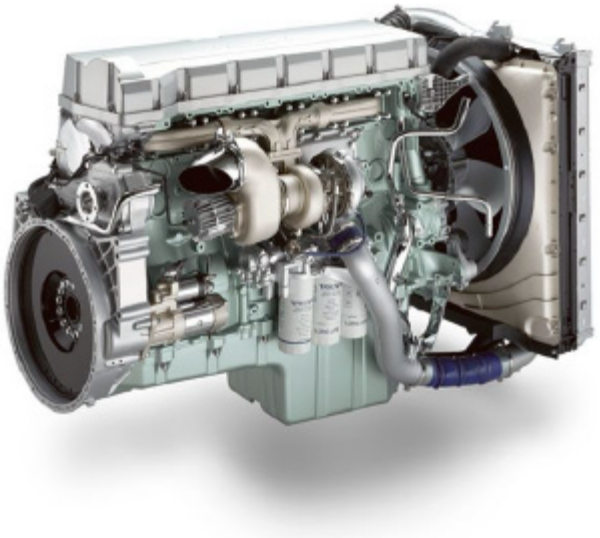
Midterm development phase:

- 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:

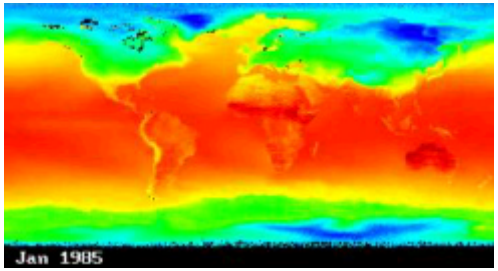
- Simulate final concept with proposed engine ratings
- Validate cooling system performance demands
- Product modification tests
- Drivecycle simulation





Driving parameters cooling system design

Climate



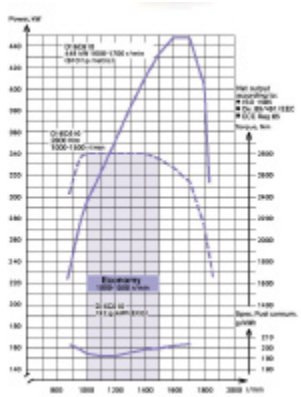
Topography

Road conditions

Application

Challenges cooling system development

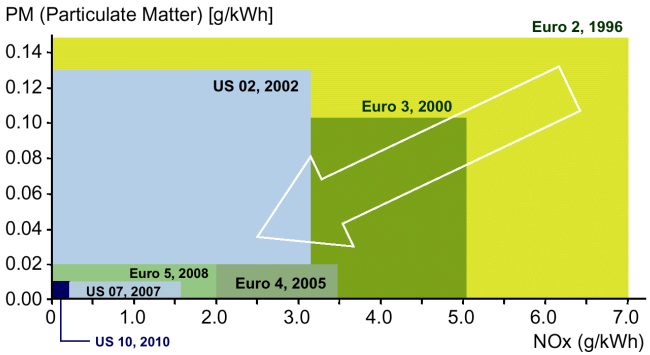
Demand for higher engine ratings → Heat rejection ↑

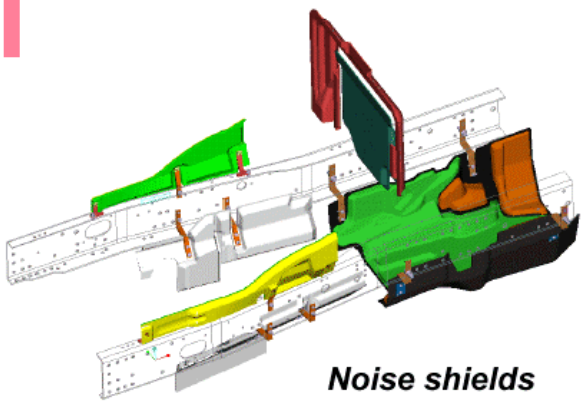


Legislative demands →
- Exhaust emission → Heat rejection ↑
- Noise emission →
  - Fan speed restriction
  - Noise shields → airflow restriction

Conflicting coolant temperature demands → Thermal management more complex

No. components needing cooling increasing → Heat rejection ↑

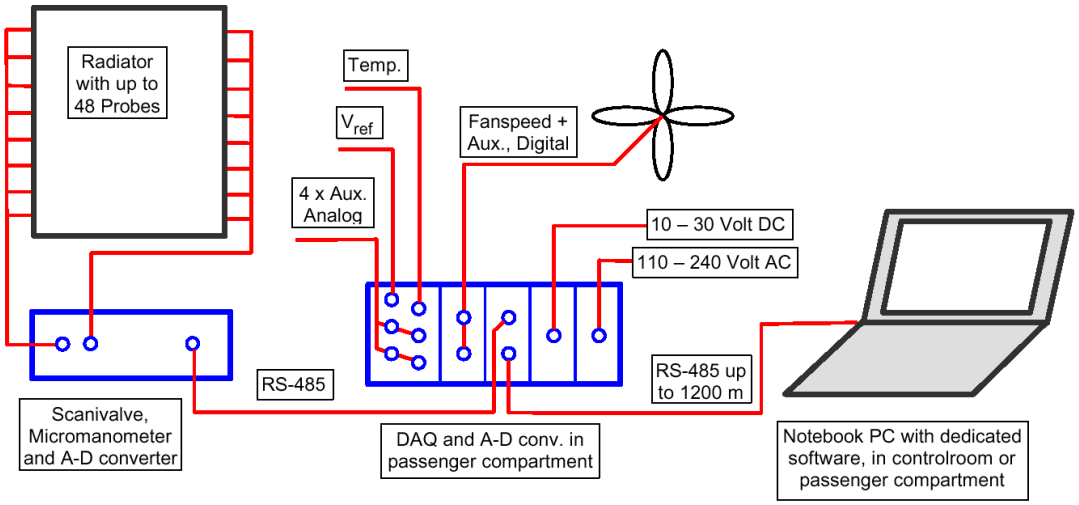




RUIJSINK
DYNAMIC ENGINEERING

Cooling air flow measurement

The MicroProbe System Set-up:



Calibration

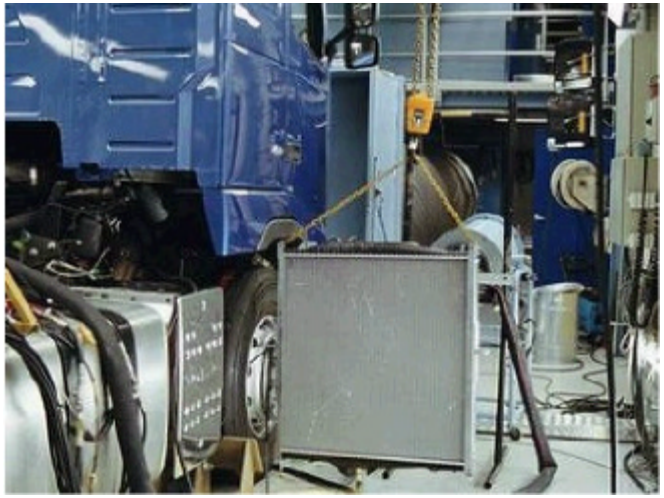
MicroProbe

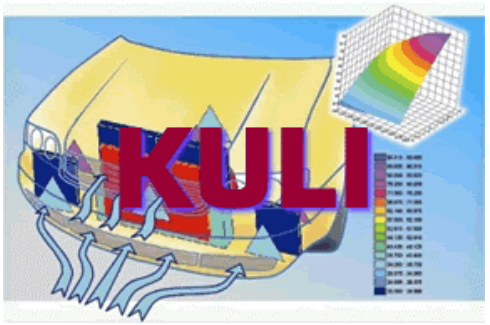
MicroProbes glued in HTX

RUIJSINK
DYNAMIC ENGINEERING

Cooling air flow measurement

In vehicle testing

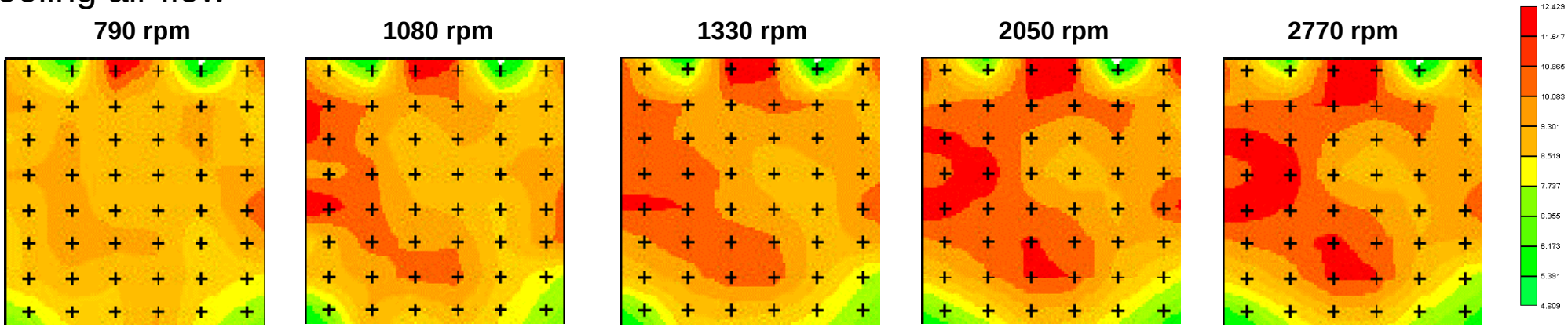




KULI Advanced

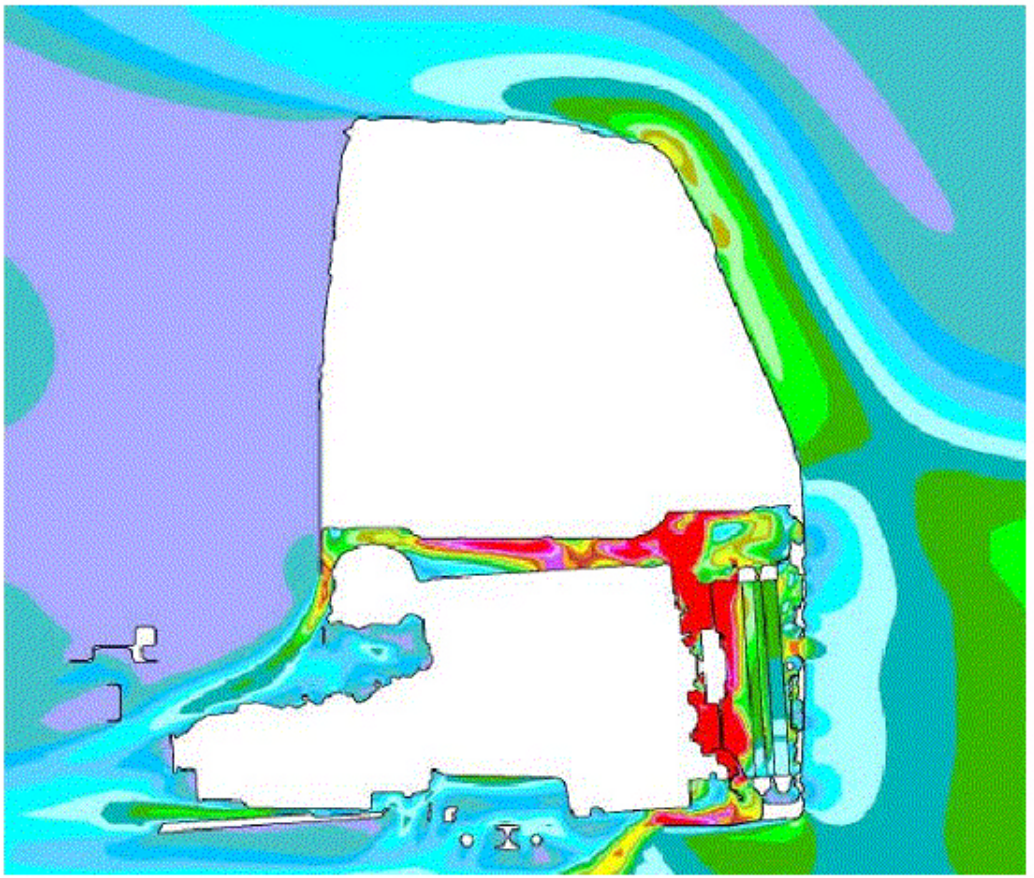
Cooling air flow

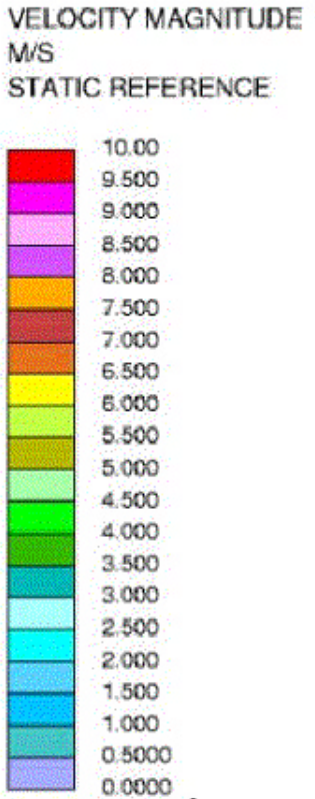
790 rpm **1080 rpm** **1330 rpm** **2050 rpm** **2770 rpm**

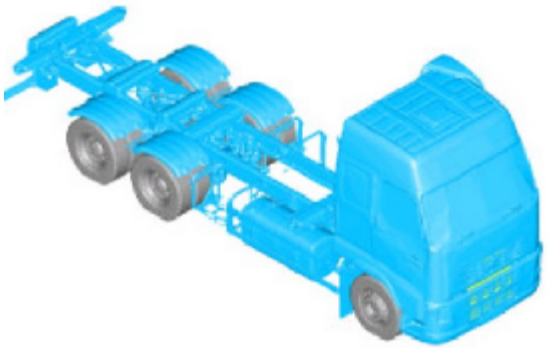


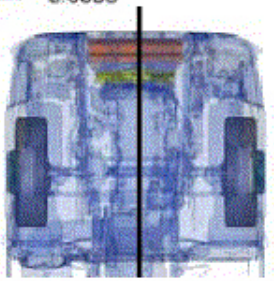
VOLVO

CFD air flow analysis



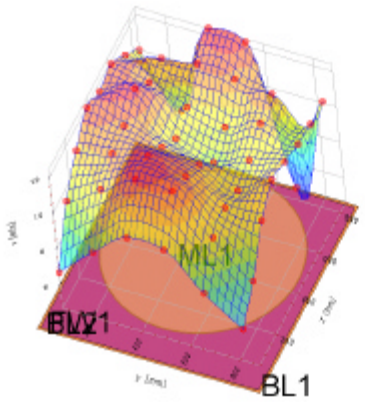




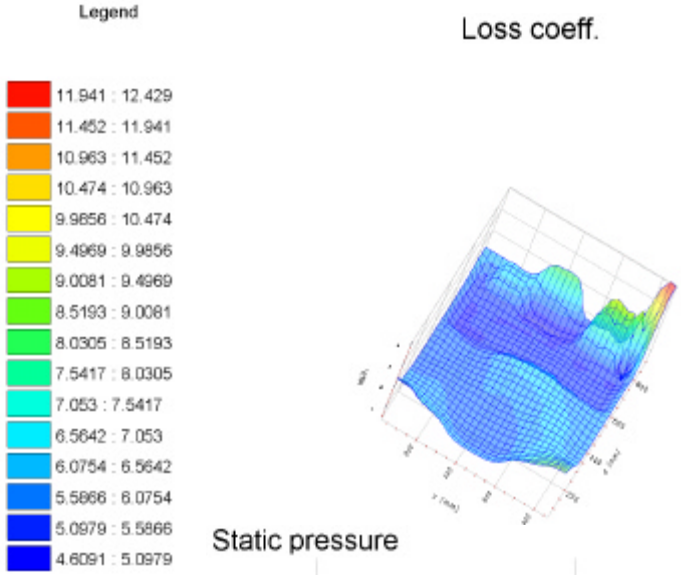


Implementing data in KULI

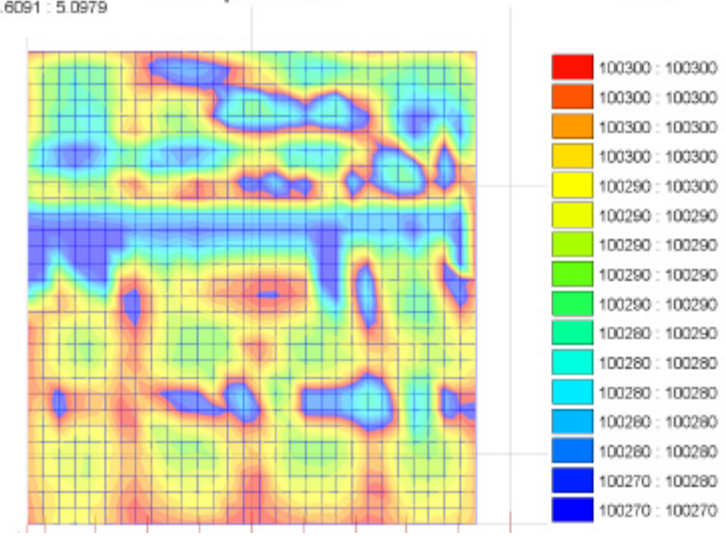
CFD velocity field



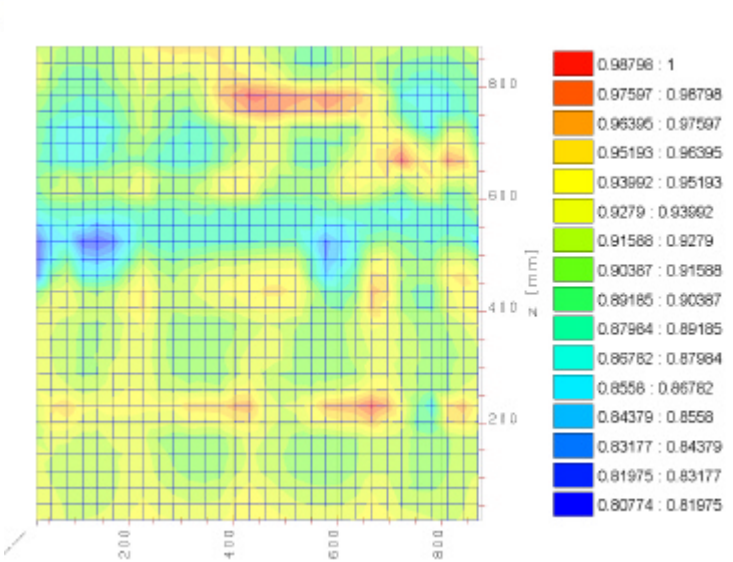
Loss coeff.



Static pressure

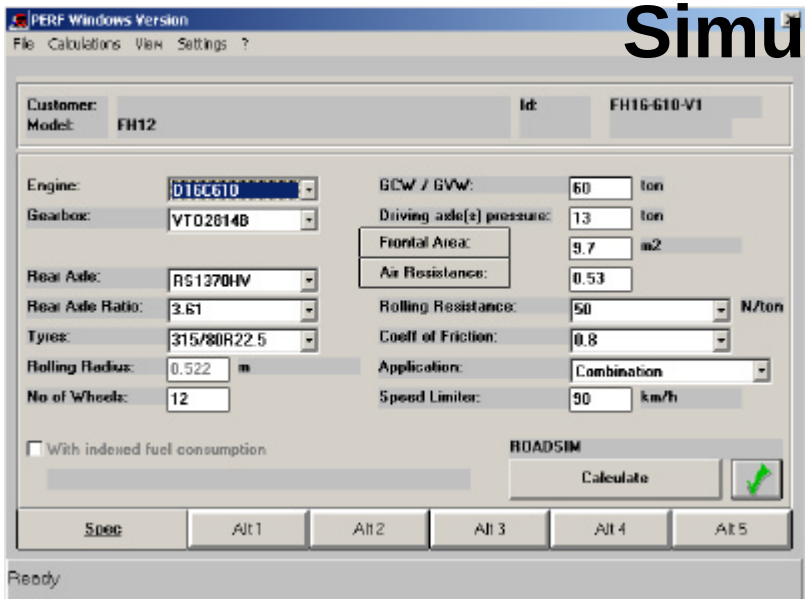


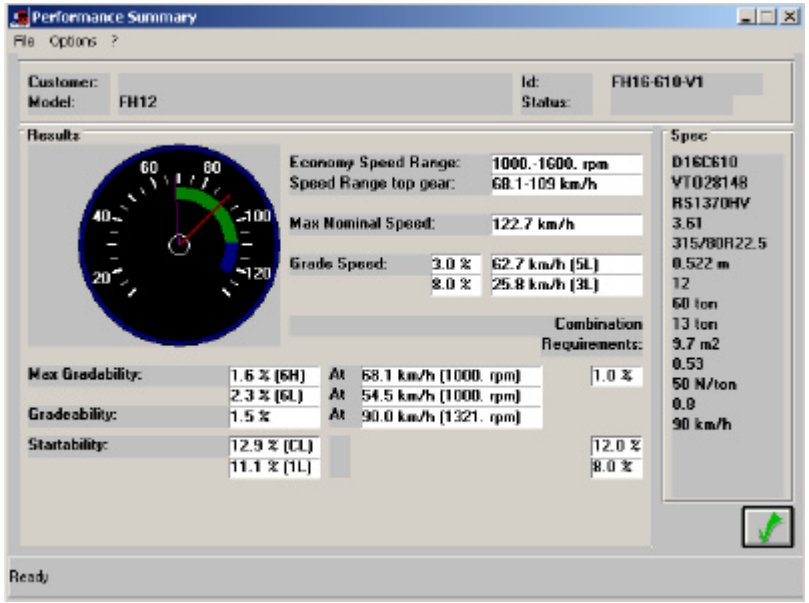
CP value



KULI Advanced needed

Simulation parameters





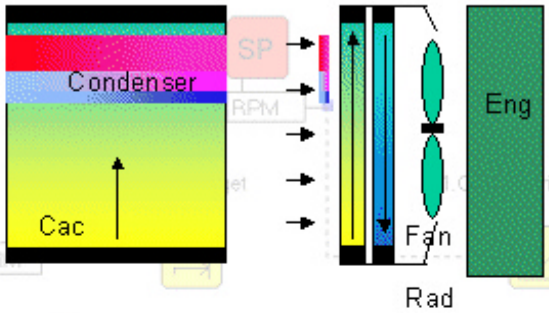
Drivecycle data acquisition

```
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                             49.8 MPH
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
```

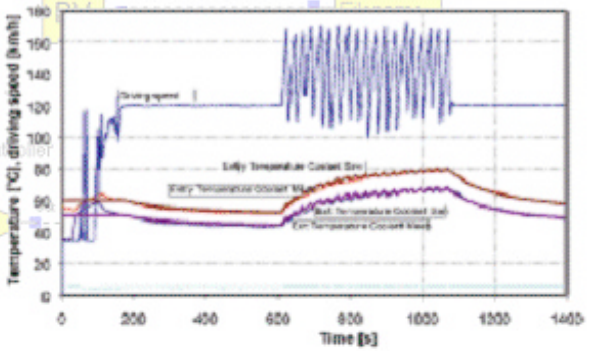
KULI Analysis

FH / NH / VN

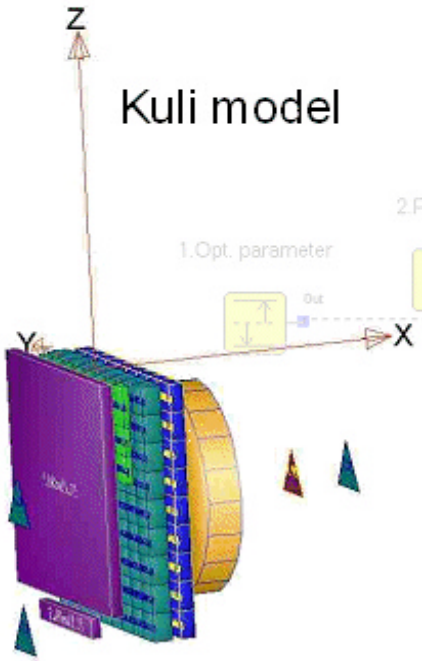
System layout



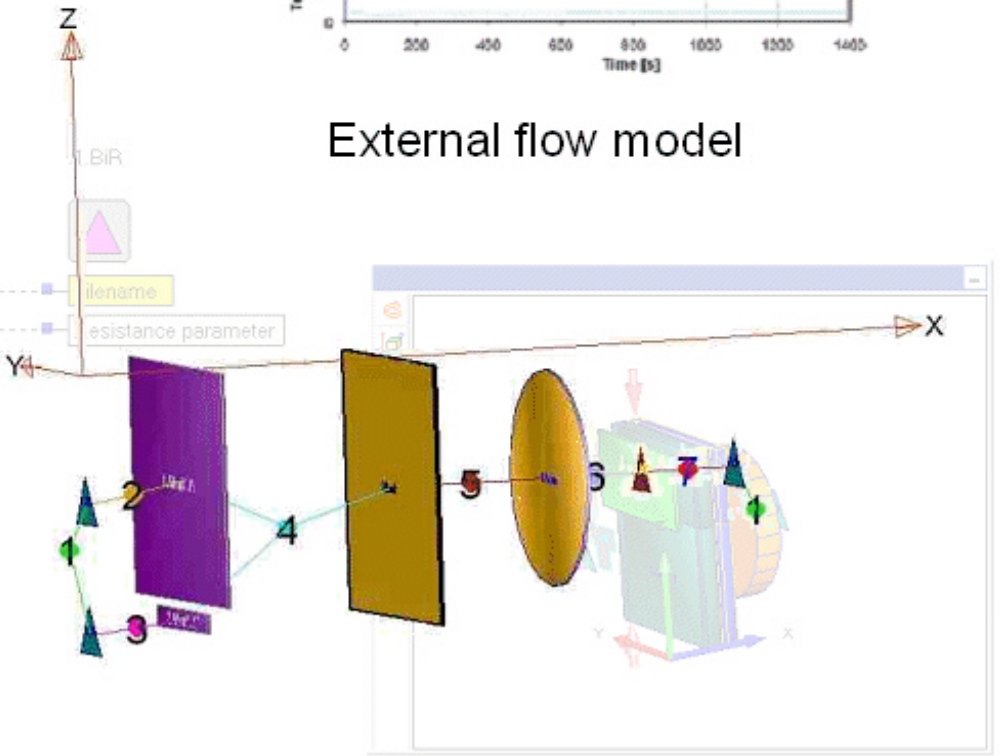
Simulation results



Kuli model

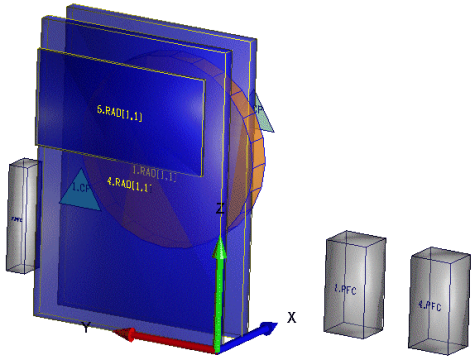


External flow model

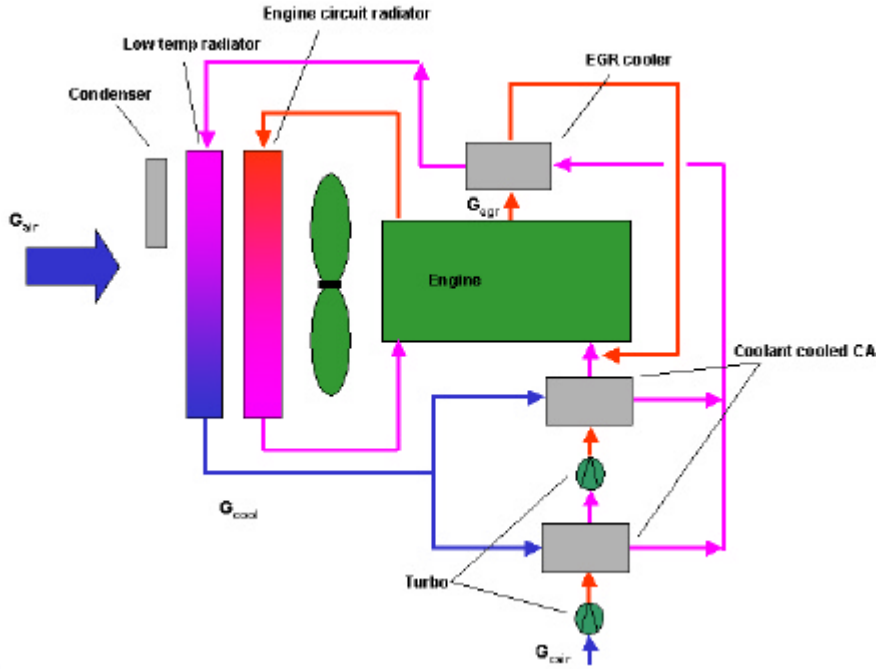


Cooling concept evaluation

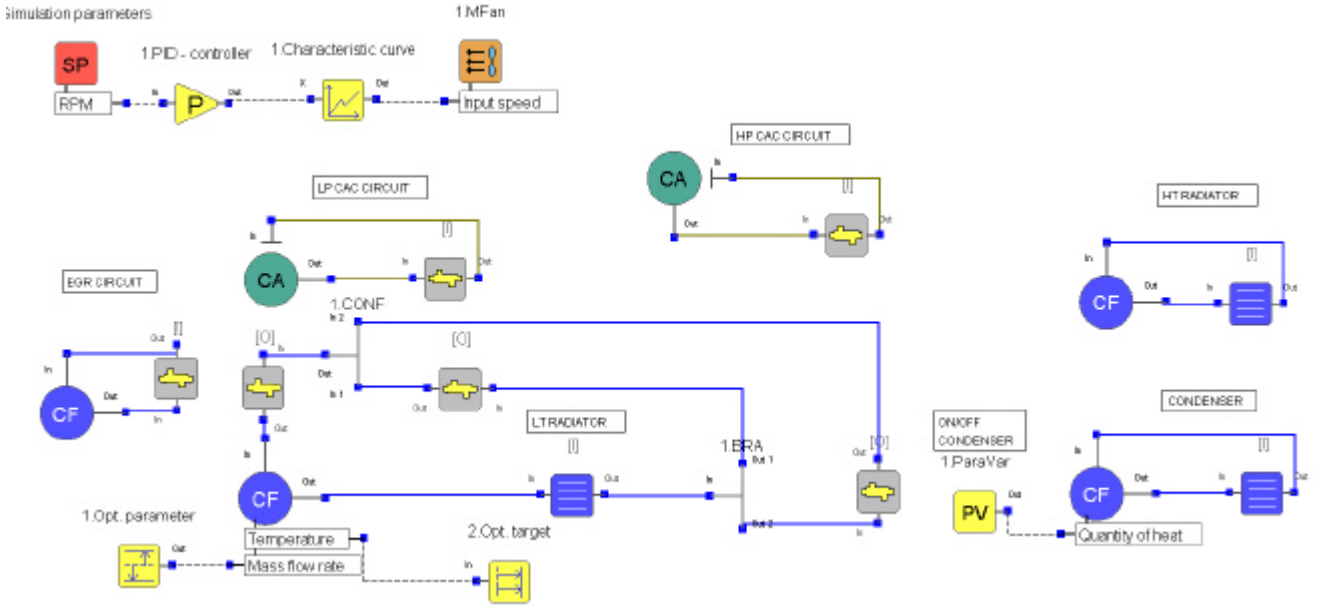
Cooling module layout



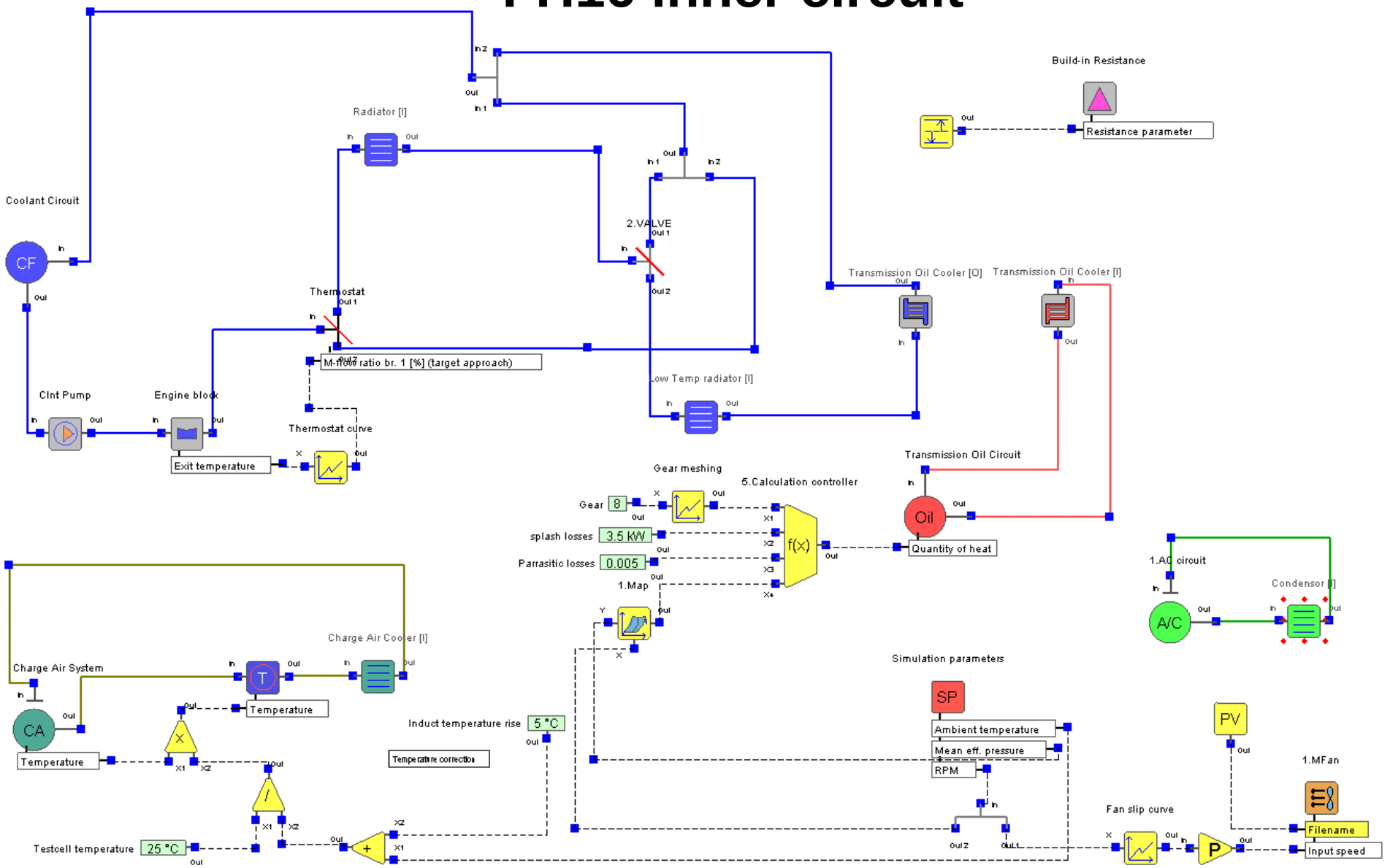
Principle flow schematic



Inner circuit

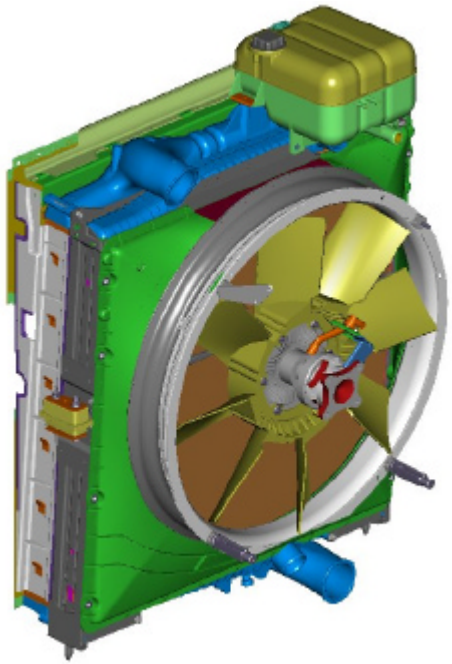


FH16 inner circuit

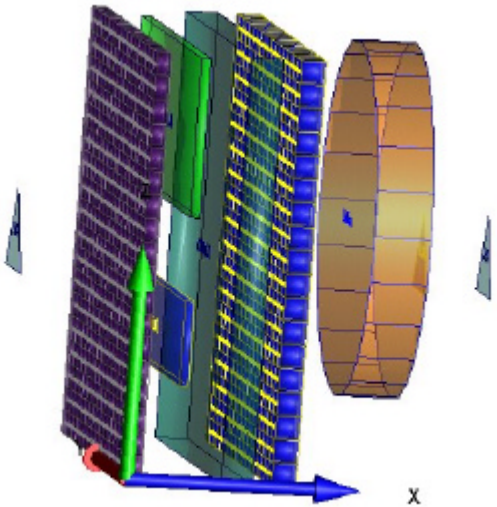


FH16 KULI model

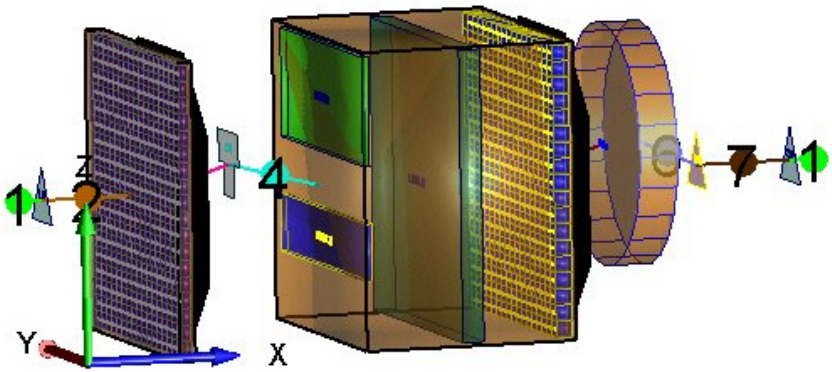
CAD-module



Cooling module layout



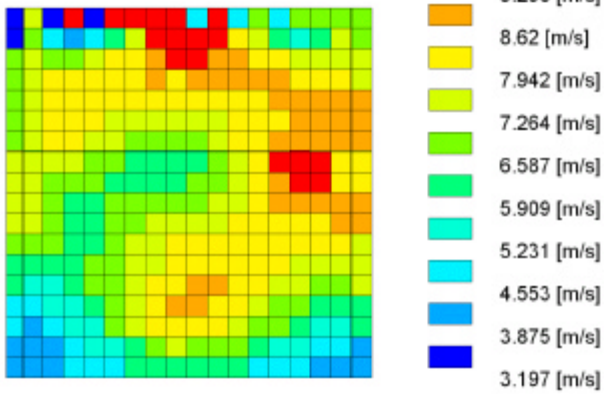
Air flow path / Air side



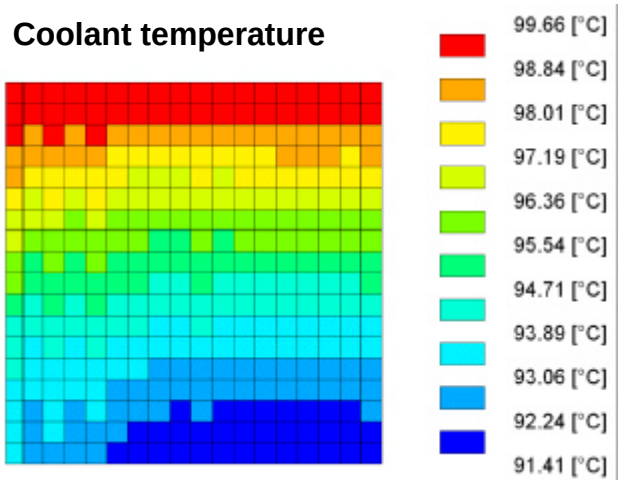
Kuli analysis results

Diagrams

Entry speed CAC



Coolant temperature



Postprocessor interface to Excel

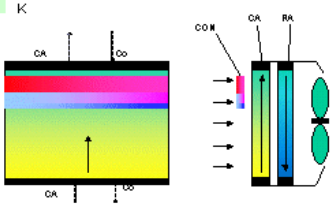
VOLVO TRUCKS

$LAT_{am.}$ 50.9 °C

$IMTD_{am.}$ 19.4 K

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

	System	W mm	H mm	D mm	Area dm²	
Condenser		814	336	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=	1.41		5.63% --- 2.88% slip	



CDYN test: input data KULI

		Cooling air			Condenser		Charge Air Cooler								Radiator					Fan						BiR		
Comment	Engine speed	G2	T2	dp2	Q_{con}	dp2	G1	T1in	p1in	T1out	η_{CAC}	dp1	IMTD	Q_{CAC}	G1	T1out	ETD	LAT $_{u}$	Q_{rad}	dp2	P_{fan}	η_{fan}	n_{fan}	ρ	Throttle no.	dp2	T_{induct}	$T_{warm-up}$
	s-1	kg/s	°C	Pa	kW	Pa	kg/s	°C	kPa	°C	%	kPa	K	kW	kg/s	°C	K	°C	kW	Pa	kW	%	s-1	kg/m³	-	Pa	°C	K
OP 1	18.3	5.04	38	47.96	8.7	-131	0.33	165	138	47.6	93.7	-9.0	9.6	40	4.77	73.0	31.8	62.7	113	628	7.9	39.1	25.1	1.02	0.139	-250	0	0.0
OP 2	21.7	5.72	38	47.70	8.6	-166	0.46	194	189	51.9	93	-12.4	13.9	67	5.57	88.6	44.1	45.1	175	817	12.3	38.7	29.5	0.98	0.142	-334	0	1.7
OP 3	25.0	6.59	38	47.60	8.5	-213	0.58	214	217	56.3	91.5	-17.1	18.3	94	6.42	92.0	44	41.9	197	1062	18.5	38.9	33.8	0.97	0.146	-446	0	2.4
OP 4	30.0	7.88	38	47.50	8.5	-292	0.65	220	204	57.4	91.4	-23.8	19.4	109	7.71	90.8	42	43.9	216	1468	30.7	38.6	39.9	0.98	0.149	-632	0	3.0

Simulated: 2005-05-25

Questions & Answers

Thank you for your attention!

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Volvo Truck Corporation

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Telefax: +46-31-22 62 03

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