International KULI User Meeting 2007

1D/3D Simulation on the Engine Room Cooling Performance of a Medium-Duty Commercial Truck

June 13th ~ 14th, 2007

HYUNDAI Motor Company
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Agenda

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- Motivation
- CFD Work Process
- Engine room configuration of a Medium-Duty Truck
- CFD Simulation
- CFD Simulation Results
- 1D Simulation
- 1D-3D Coupling Simulation
- Parameter study
- Summary and Conclusions

Motivation

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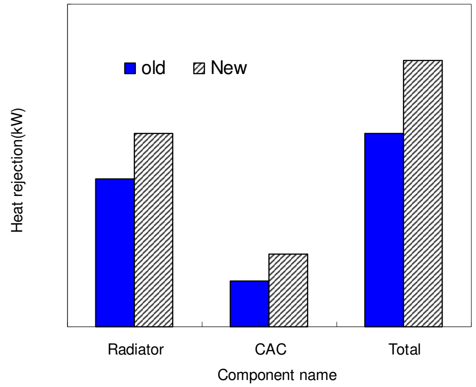
■ Newly developing engine requires enhanced cooling performance
- Higher heat rejection by coolant
- Higher pressure and temperature for CAC inlet
- Improving Cooling Package Capabilities



■ Efficient process integration of engine room thermal & flow analysis in the vehicle development stage
- 3D simulation can show many details and give insight into flow behavior
- It has long computation times and need a experienced engineer

■ Request for increased accuracy in 1D Simulation results
- A combined simulation of 1D and 3D techniques make sense and delivers results that highly reliable.

CFD Work Process

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Pre-processing stage

CATIA model input through the CAD direct interface of the Hypermesh or Pro-AM

CAD clean-up and make shell surface using Hypermesh or Pro-AM

Automatic engine room mesh generation using ES-UHOOD (Hexa and Trimmed cell mesh)

Problem and boundary setting using STAR-CD

Solving & Post-processing stage

Two-phase engine room CFD simulation using STAR-CD

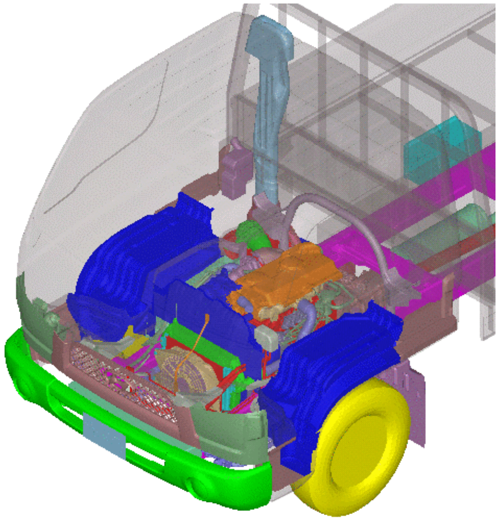
Input data generation in terms of component experiment data

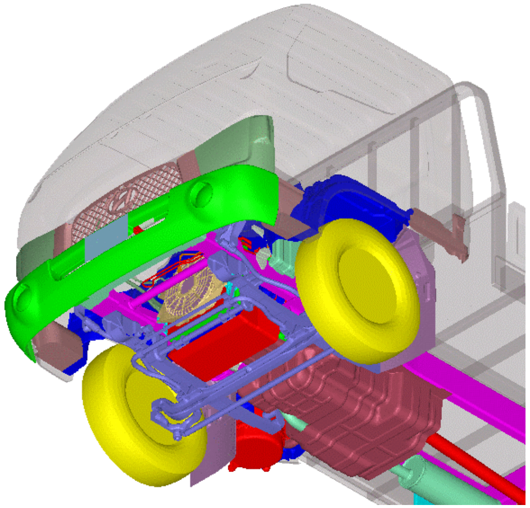
- Mass flow rate
- Flow distribution in the engine room
- Pressure distribution in the engine room
- Coolant temperature of the radiator inlet
- Charged air temperature of the CAC outlet
- Air temperature of the radiator and CAC
- Air temperature distribution in the engine room

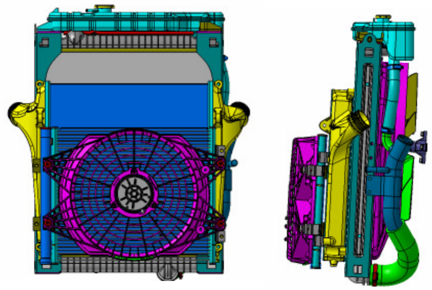
Visualization using STAR-CD

Engine Room Configuration of Medium-Duty Truck

• Cooling package Layout and specification



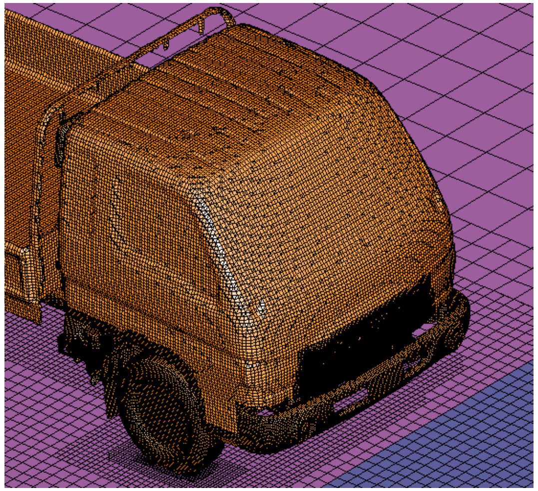


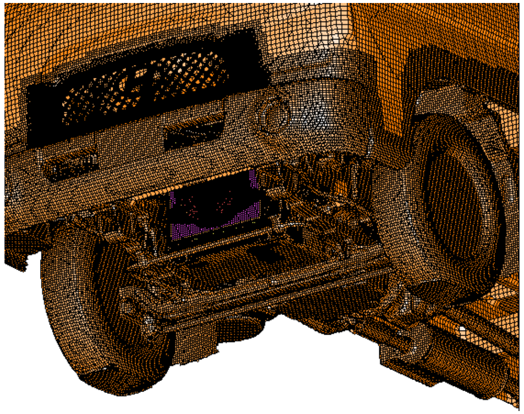


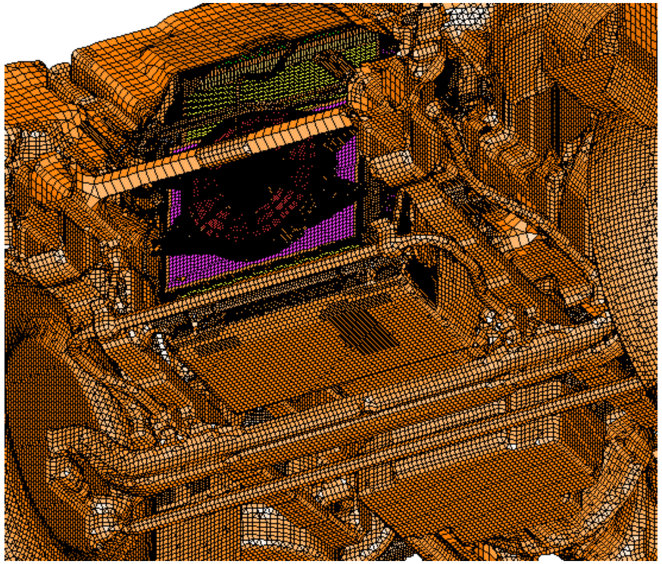
Item		Specification
Max. Power(PS/RPM)		150/2500
Radiator (W x H x T)		517 x 600 x 45.5
CAC (W x H x T)		470 x 495 x 50
A/C condenser		468 x 372 x 18
E-Fan		Φ321 x 4blade
M-Fan	Size	Φ500 x 7blade
	Drive ratio	1.34
	Slip rate	9%

CFD Simulation – Mesh Generation

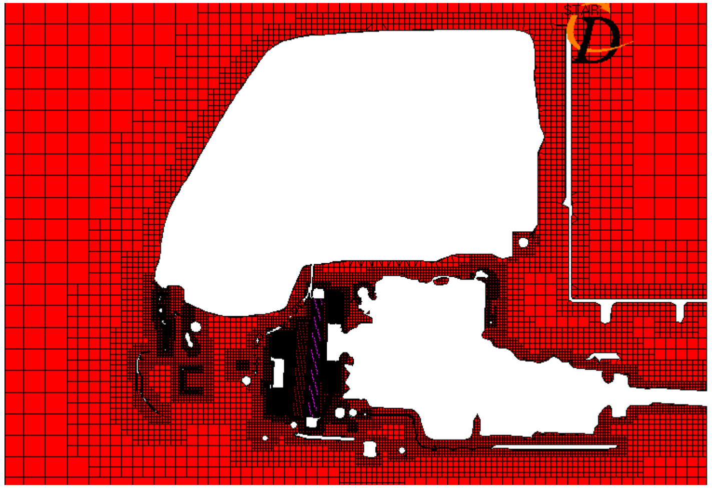
- Mesh configuration

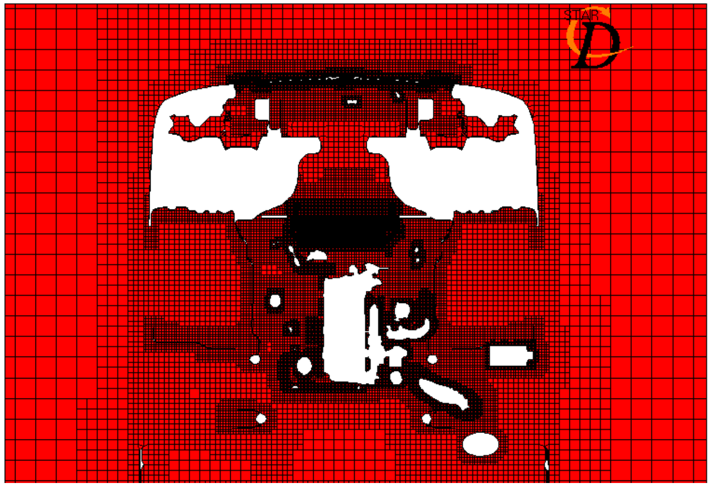






- Inner volume mesh structure





CFD Simulation – Boundary Condition Ⅰ

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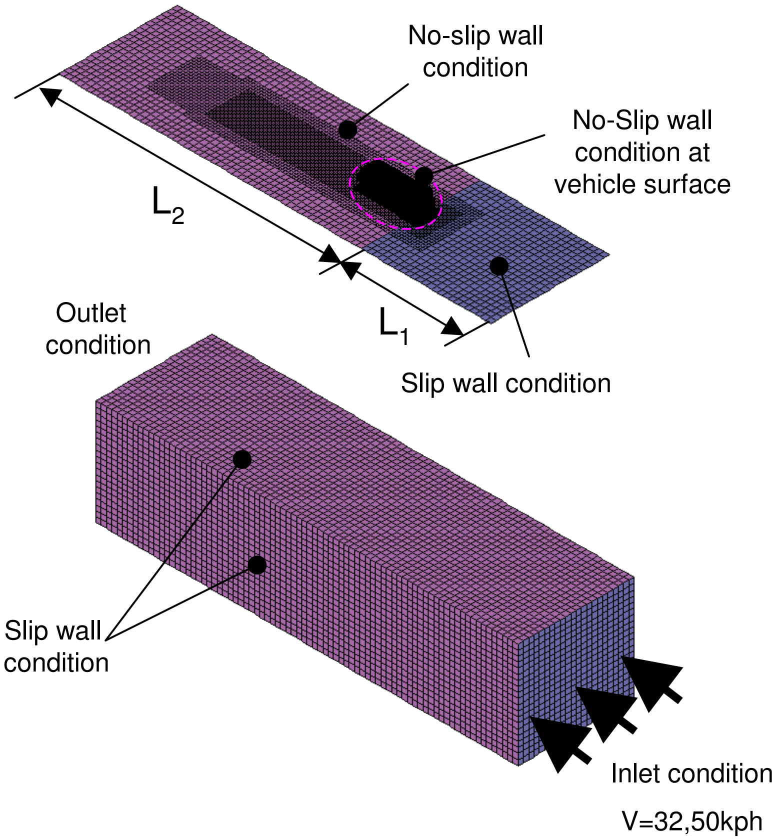
● Wind tunnel condition

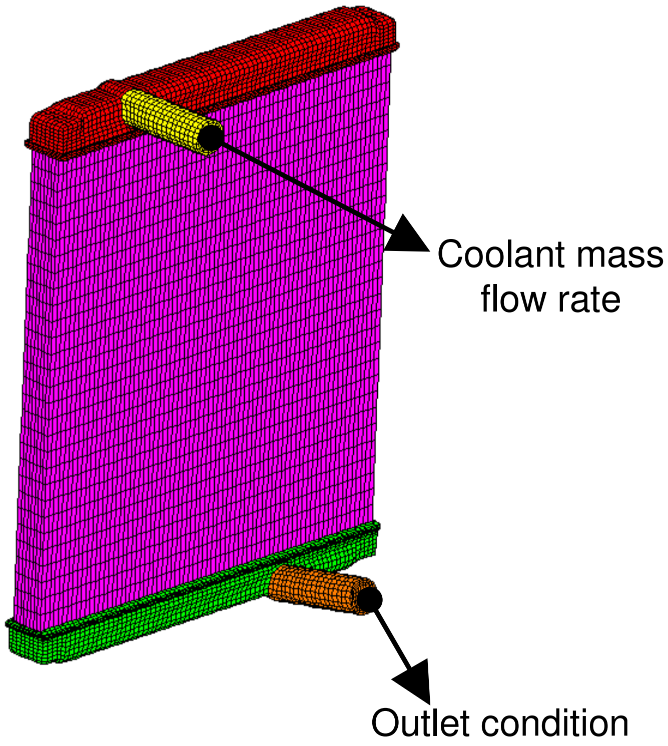
Item		Boundary condition
Inlet region		Driving speed
Outlet region		Outlet condition
Ground	L1 region	Slip wall
	L2 region	No-Slip wall
Side & Upper region		Slip wall
Vehicle surface		No-Slip wall

Item	Dimension (m)
L	48.9
L1	14.1
L2	34.5
W	14.8
H	11.3

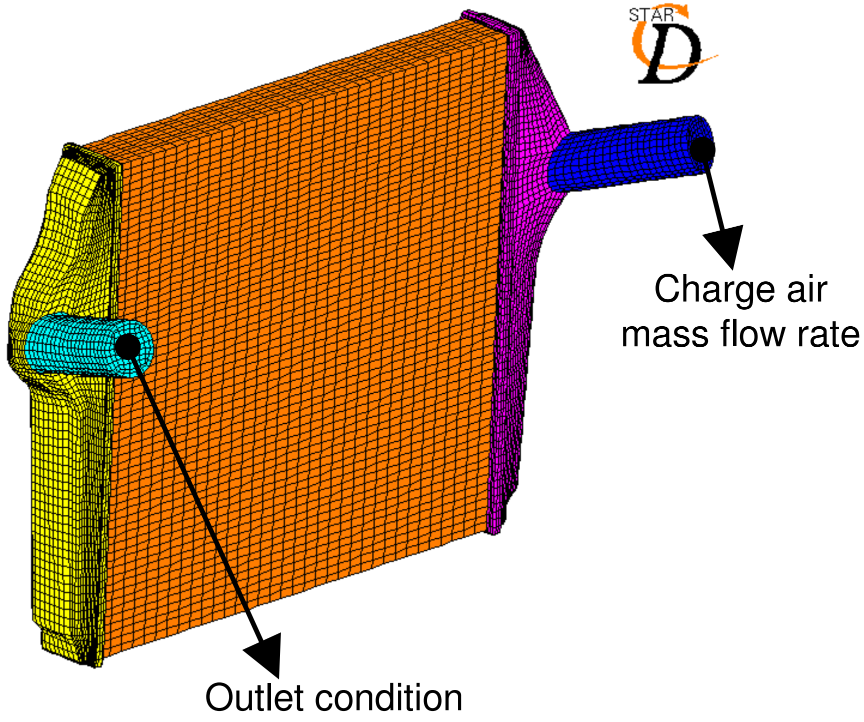


- **The under-relaxation factors for U,V,W were fixed to 0.3**
  for k,ε were fixed to 0.7
  for p were fixed to 0.2
- **Convergence Criteria**
  The residuals of all variables — a level of less than 0.1%
- **The calculation were run on ALTIX 2 super computer**
- **The execution time for achieving full convergence took about 28 hours per case**

● Radiator - coolant side



● Charge Air Cooler - charge air side

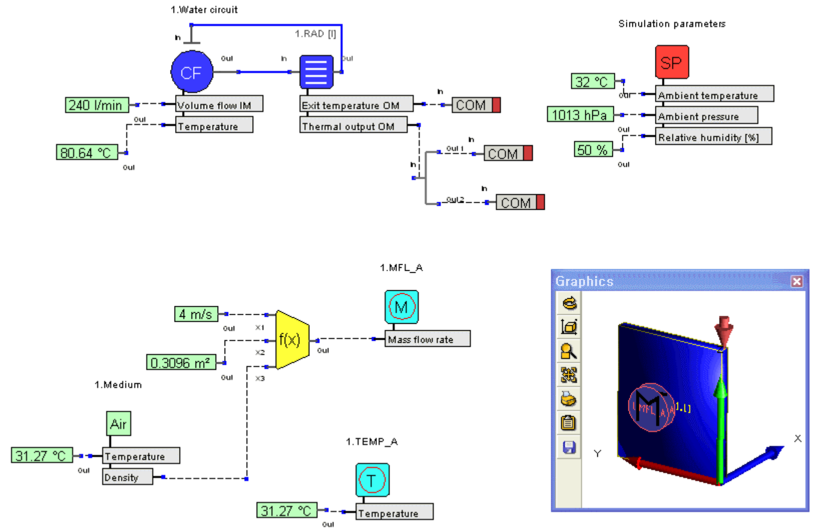


CFD Simulation – Input Conditions

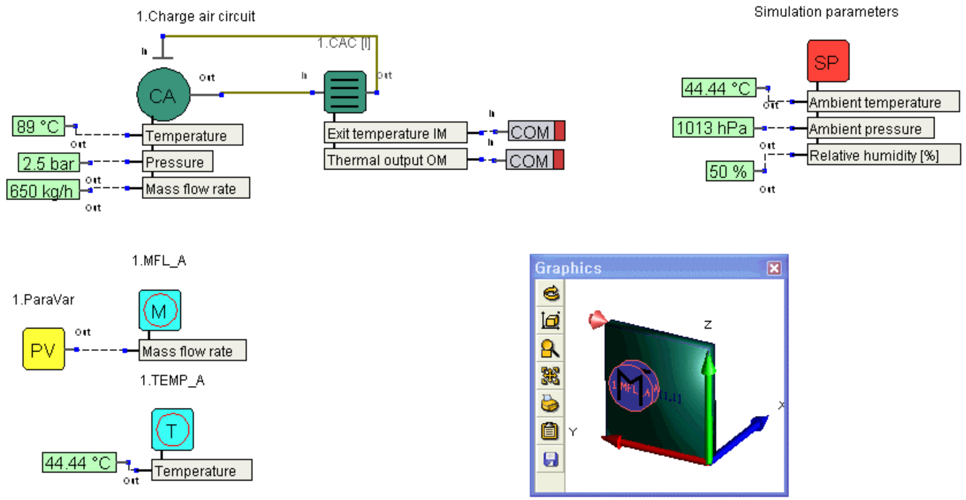
Simulation Conditions	Data	Resource	Remark
Vehicle speed (KPH)	32 / 50	Given	
Environment temperature (℃)	24	Given	
M-Fan speed (rpm)		Given	
E-Fan speed (rpm)	2200	Given	
Coolant inlet temperature (℃)		Simulation result	To find ACT
Coolant mass flow rate (LPM)	230	Given	
Charged air inlet temperature (℃)		Given	
Charged air inlet mass flow (kg/h)		Given	
Charged air outlet temperature (℃)	-	Simulation result	To find IMTD
Condenser heat rejection rate (W)	9256.9	given	Heat source treatment
Pressure drop in radiator and CAC air side (ΔP)	-	Test data	Porosity treatment
Pressure drop in radiator coolant side and CAC charge air side (ΔP)	-	Test data	Porosity treatment
Pressure drop in condenser air side (ΔP)		Test data	Porosity treatment

Test Bench Simulation - Heat Rejection

Test bench - Radiator



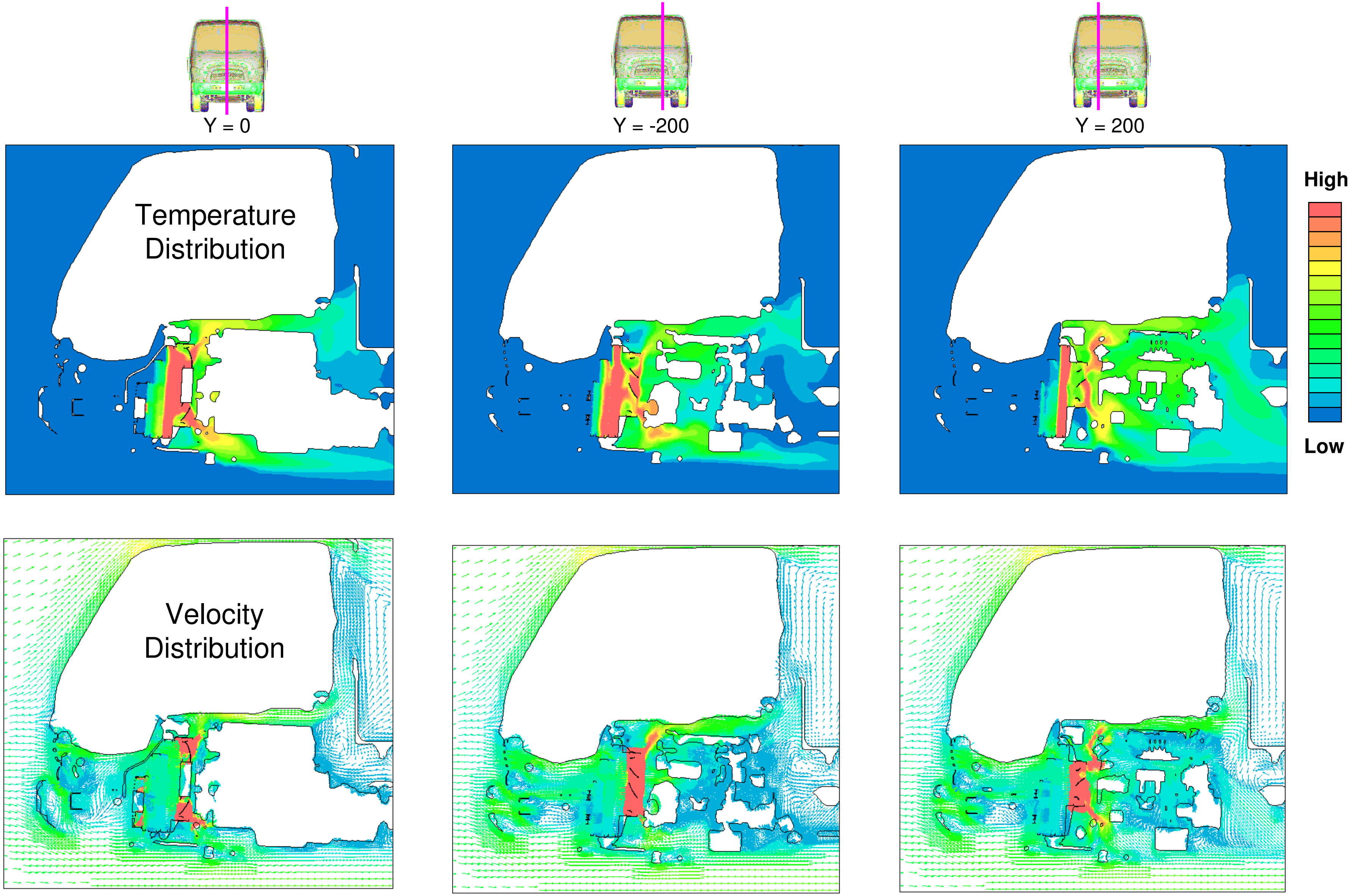
Test bench – Charge air cooler



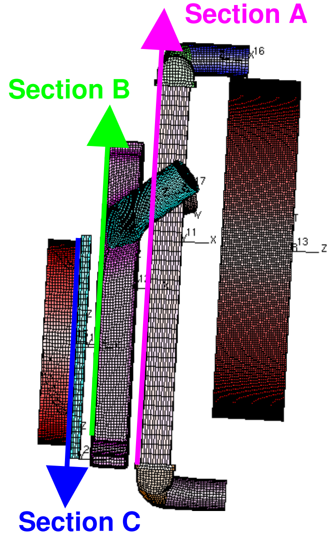
Hxinput file for 3D simulation

NAME		NAME	
Radiator		Intercooler	
METHOD		METHOD	
3		3	
ATYPE		ATYPE	
102		112	
0		0	
CTYPE		CTYPE	
105		115	
0		0	
AUTYPE		AUTYPE	
101		111	
ADTYPE		ADTYPE	
103		113	
CUTYPE		CUTYPE	
106		114	
CDTYPE		CDTYPE	
104		116	
URFQ		URFQ	
0.5		0.5	
ISTART		ISTART	
1		1	
NHXC		NHXC	
70		90	
NHXA		NHXA	
10		9	
…		…	
…		…	
…		…	
QADAT		QADAT	
1.28948	64893.1	1.16161	44568.8
1.93422	86512.1	1.74242	47138.3
2.57897	105690	2.32323	48760.0
3.22371	126882	2.90403	50019.8
3.86845	147480	3.48484	51147.8
4.51319	163982	4.06565	52230.2
5.15793	178250	4.64645	53195.7
0.0	0.0	0.0	0.0
		END	

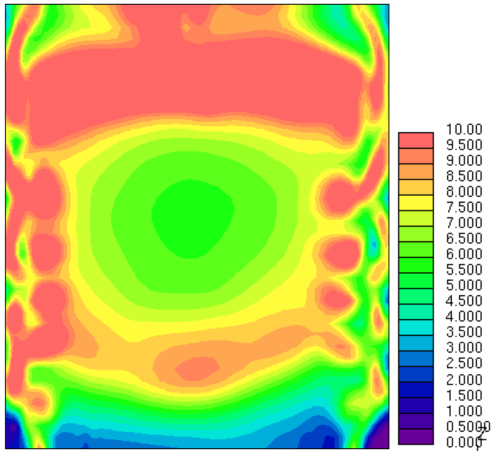
CFD Simulation - Thermal and Flow Distribution

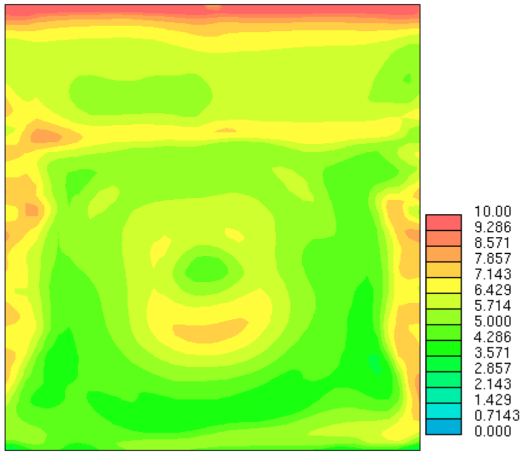


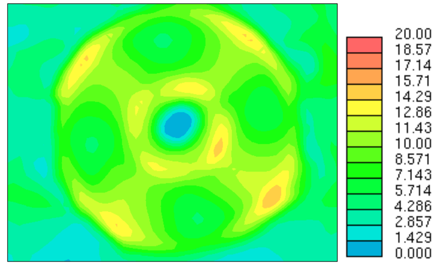
CFD Simulation - Velocity Distribution



- 32KPH case





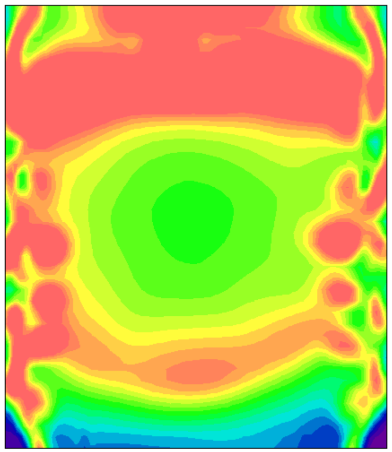


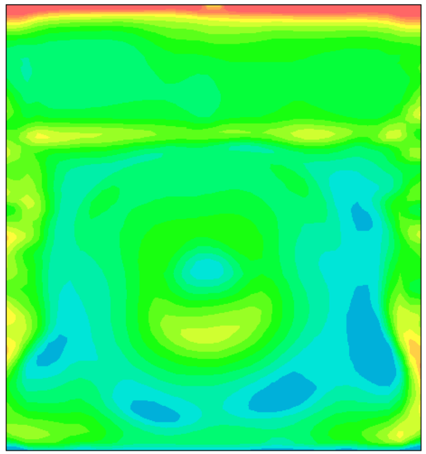
Radiator (Section A)

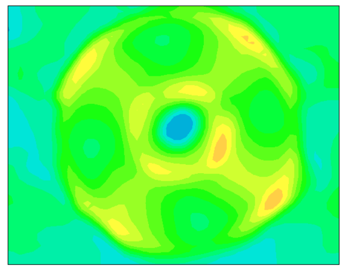
Charge air cooler(Section B)

Condenser (section c)

- 50KPH case

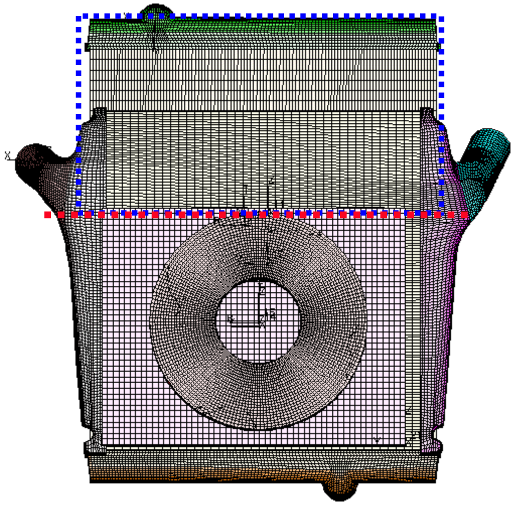




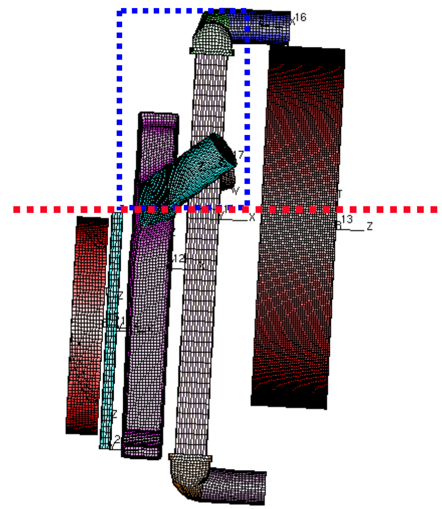


CFD Simulation – Data Acquisition

32KPH HOT		Area(m^2)	Air mass flow ate(m^3/sec) [ ] : kg/sec	Pressure (Pa) P_{front}	Pressure (Pa) P_{rear}	Pressure (Pa) ΔP	Air temperature (℃) T_{front}	Air temperature (℃) T_{rear}
Radiator	Upper region	0.129	0.819[0.941]	-	-	-	45.42	79.48
	Total	0.311	1.647[1.834]	-306	-556	250		
CAC	Upper region	0.066	0.308[0.364]	-	-	-	33.67	52.04
	Total	0.238	1.054[1.216]	-67	-330	263		
Condenser		0.161	0.547[0.646]	4	-74	78	27.31	39.70
M-FAN		0.199	1.868[1.926]	-590	-238	352	57.94	55.44
E-FAN		0.070	0.427[0.504]	-88	61	149	25.64	25.69



Case name	Heat exchanger	Stream	Temperature(℃) Inlet	Temperature(℃) Outlet	Pressure drop (Pa)	Heat rejection (W)	Performance (℃) ACT	Performance (℃) IMTD
32KPH HOT	Radiator	Air	44.44	79.40	249	**66578**		
		Coolant			**36955**			
	CAC	Air	33.65	51.47	263	**22814**		
		Charge air			**5462**			



: Upper region : Reference line

1D Simulation – Component Modeling

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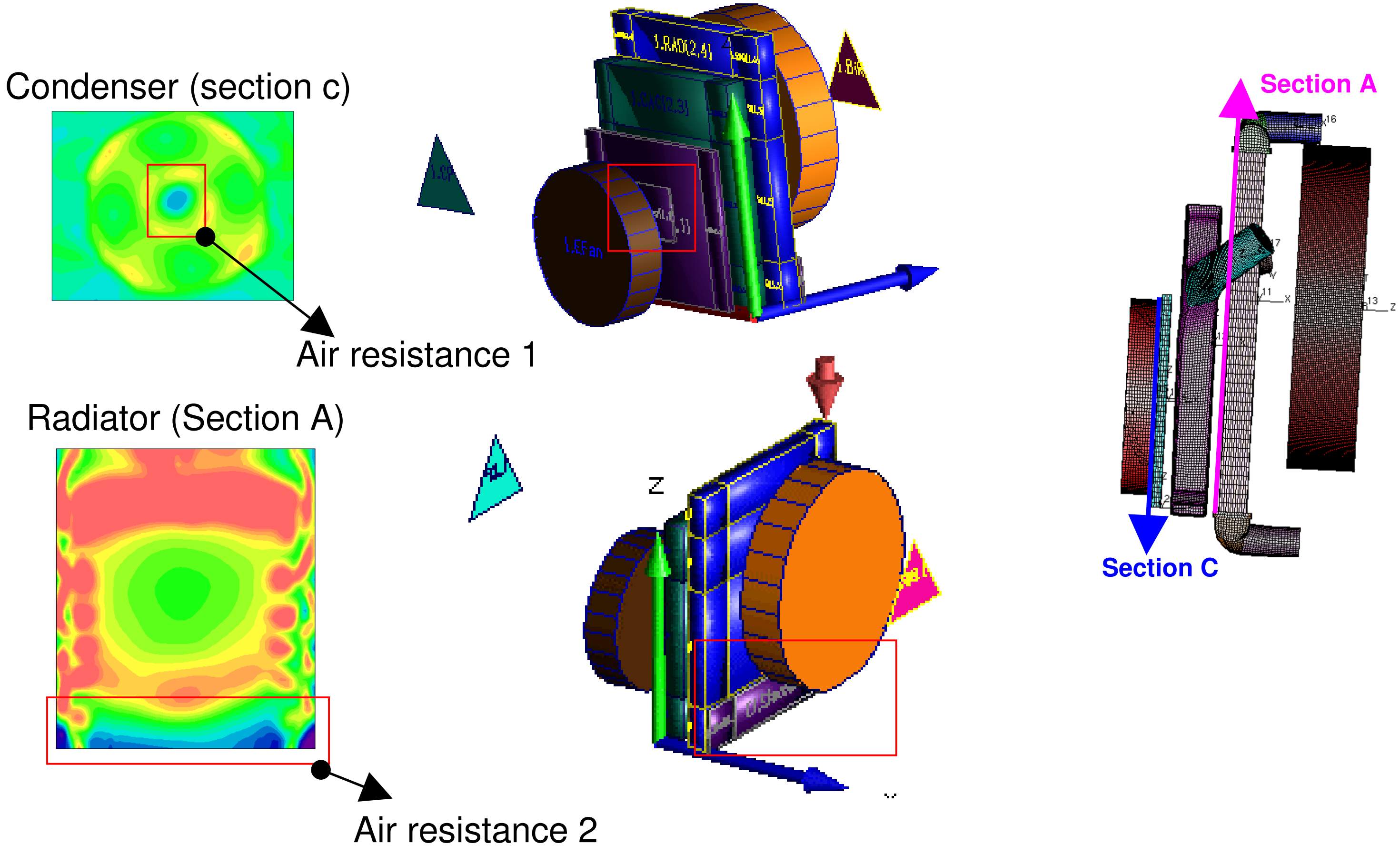
- Splitting of Air Side Component into Parts and Applying Air Resistance

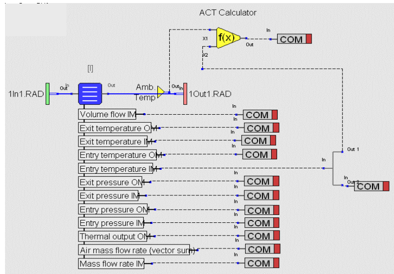


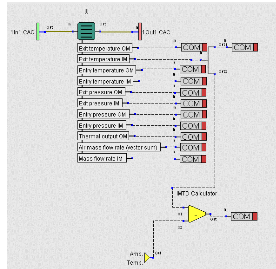
- Model Adjustment

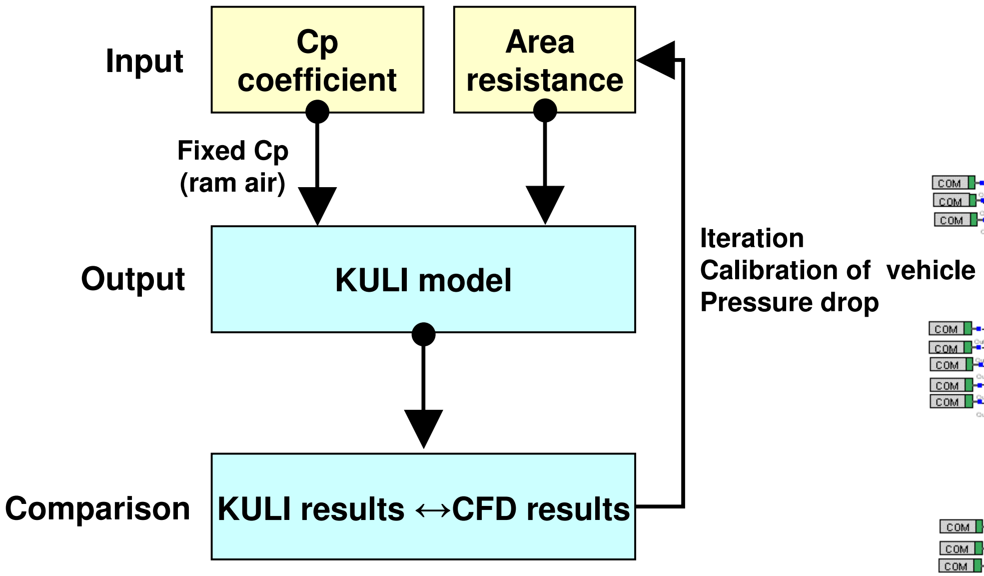
- The effect of the vehicle on the cooling air flow through cooling package can be reduced to two elementary effects : Ram effect, vehicle pressure drop effect

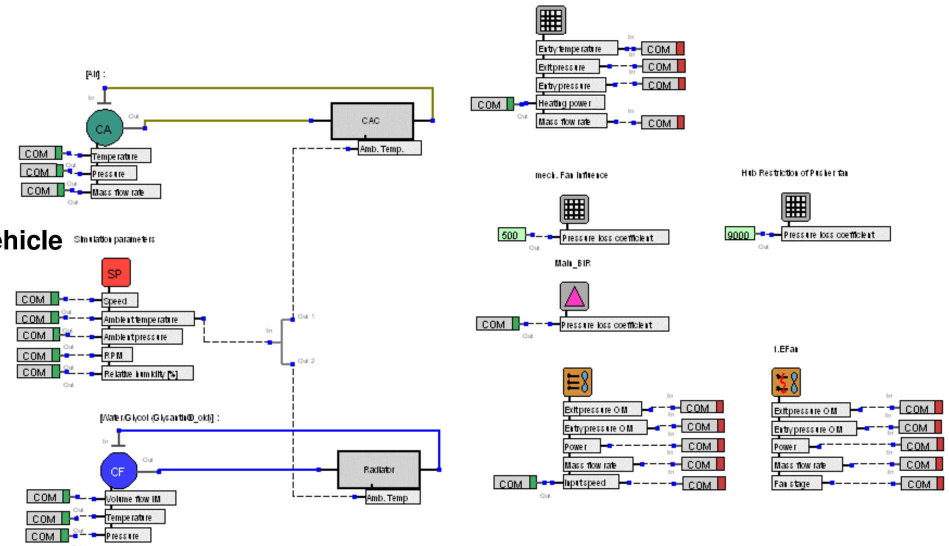
STEP 1)
Adjusting the 1D cooling system to a single CFD simulation point

STEP 2)
Adjusting the 1D cooling system to all the CFD simulation points









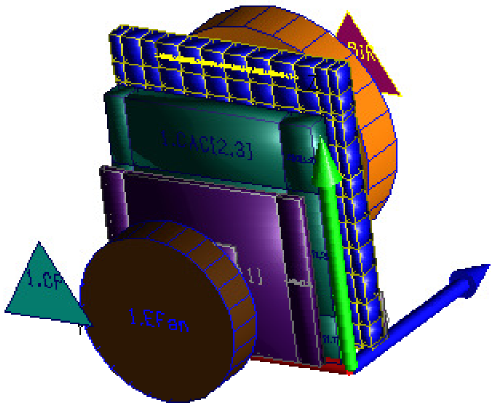
- Determination of the BIR

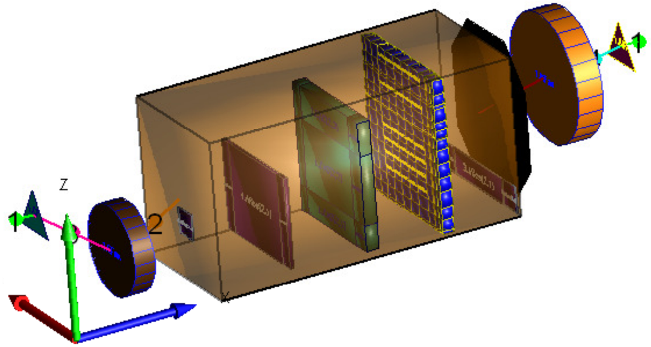
ITEM			Cold Simulation		Warm simulation	
			low speed	high speed	low speed	high speed
Simulations parameter	T	℃	24	24	24	24
	p	hPa	1013	1013	1013	1013
	X	%	50	50	50	50
	n Engine	RPM				
	v vehicle	km/h	32	50	32	50
Cooling Circuit	V_pt	l/min	240.00	240.00	240.00	240.00
	p_IM_IN	bar	1.00	1.00	1.00	1.00
	T	℃	24	24	89	89
Charge Air Circuit	m_pt	kg/h				
	p_IM_IN	bar	2.07316	2.07316	2.07316	2.07316
	T	℃	24	24	168	168
mechanical Fan	n	1/min				
BiR	Zeta	-	225.78125	220.3125	198.4375	198.4375
	min Zeta	-	100	100	100	100
	max Zeta	-	800	800	800	800

RAD	$T_{Rad,\ Coolant\ IN}$	K	0.0	0.0	0.0	0.0
	$T_{Rad,\ Coolant\ out}$	K	0.0	0.0	-0.4	0.0
	$T_{Rad,\ Air\ IN}$	K	0.0	0.0	2.9	7.2
	$T_{Rad,\ Air\ out}$	K	0.0	0.0	3.1	3.9
	Cooling air flow	%	0.0	0.0	0.0	-0.2
CAC	$T_{CAC,\ Charge\ Air\ IN}$	K	0.0	0.0	0.0	0.0
	$T_{CAC,\ Charge\ Air\ out}$	K	0.0	0.0	-1.4	3.8
	$T_{CAC,\ Air\ IN}$	K	0.0	0.0	0.5	3.8
	$T_{CAC,\ Air\ out}$	K	0.0	0.0	1.1	3.3
	Cooling air flow	%	-0.9	-1.0	-0.7	-1.4
IMTD		K	-	-	-1.4	3.8
ACT		K	-	-	0.0	0.0

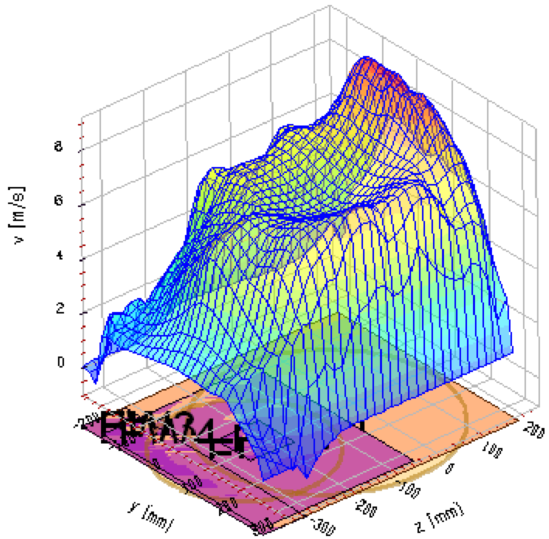
1D-3D Coupling Simulation – Resistance Matrix

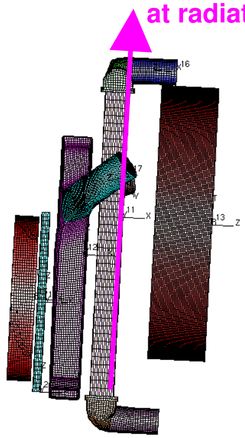
- Cooling system with split radiator and air path





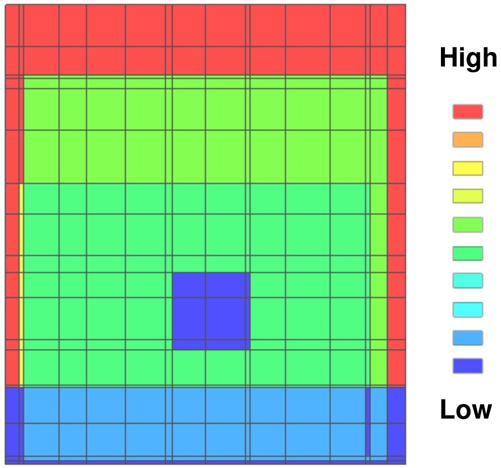
- 1D-3D Interface : Velocity Profile at the Cross section of Radiator Outlet



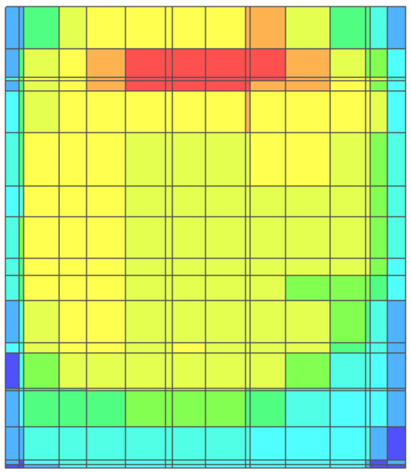


1D-3D Coupling Simulation – Result Comparison

Cooling air speed : 1D only

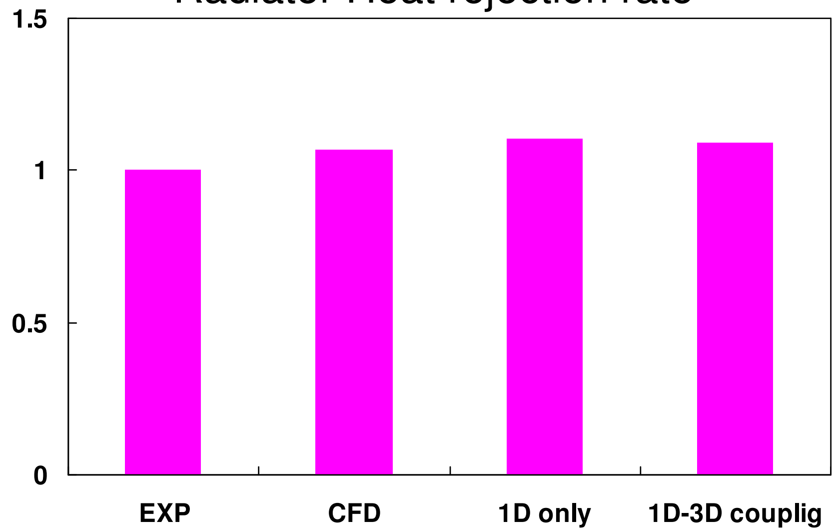


Cooling air speed : 1D-3D coupling

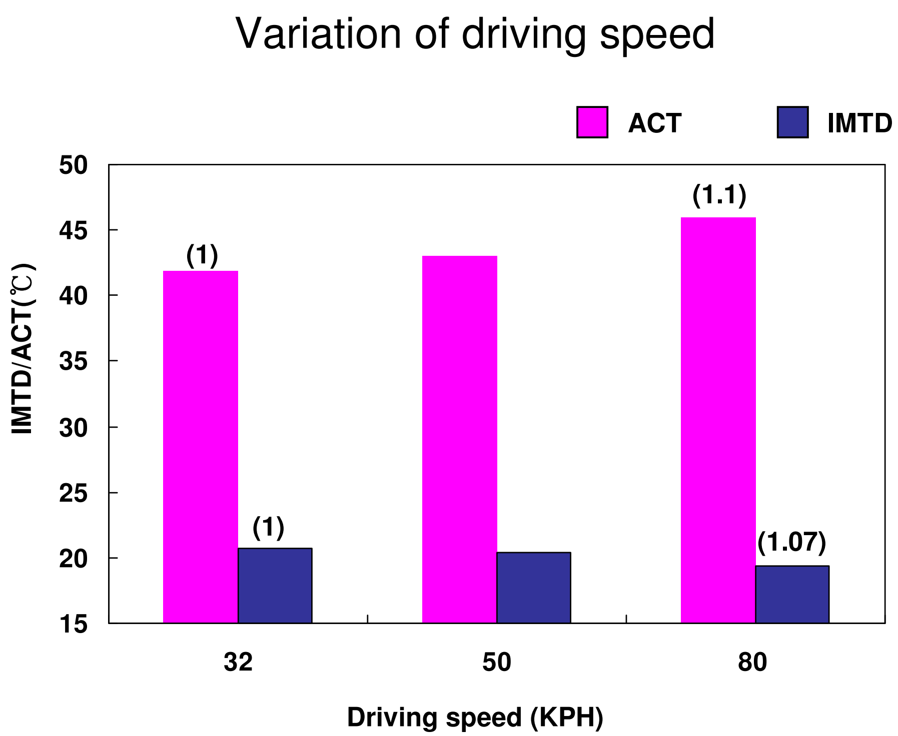


	1D Only	1D-3D Coupling	Deviation
Radiator Heat Rejection (kW)	68,051kW	65,261kW	4,3%
Coolant Exit Temperature (°C)			2,1K

Radiator Heat rejection rate



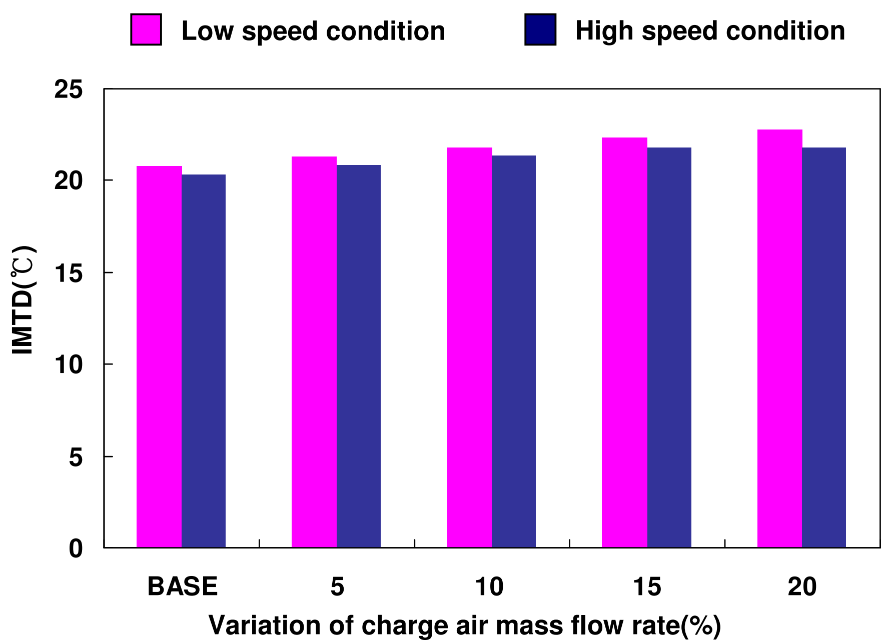
Parameter study – Driving speed



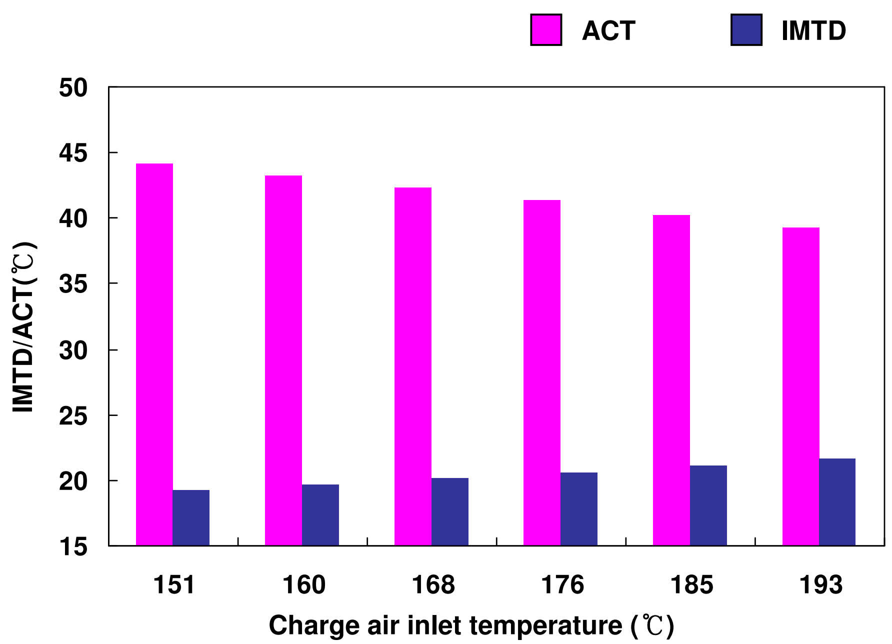
ACT = 110- Radiator inlet temperature + ambient temperature
IMTD = CAC outlet temperature – ambient temperature

Parameter study – Charge Air Cooler

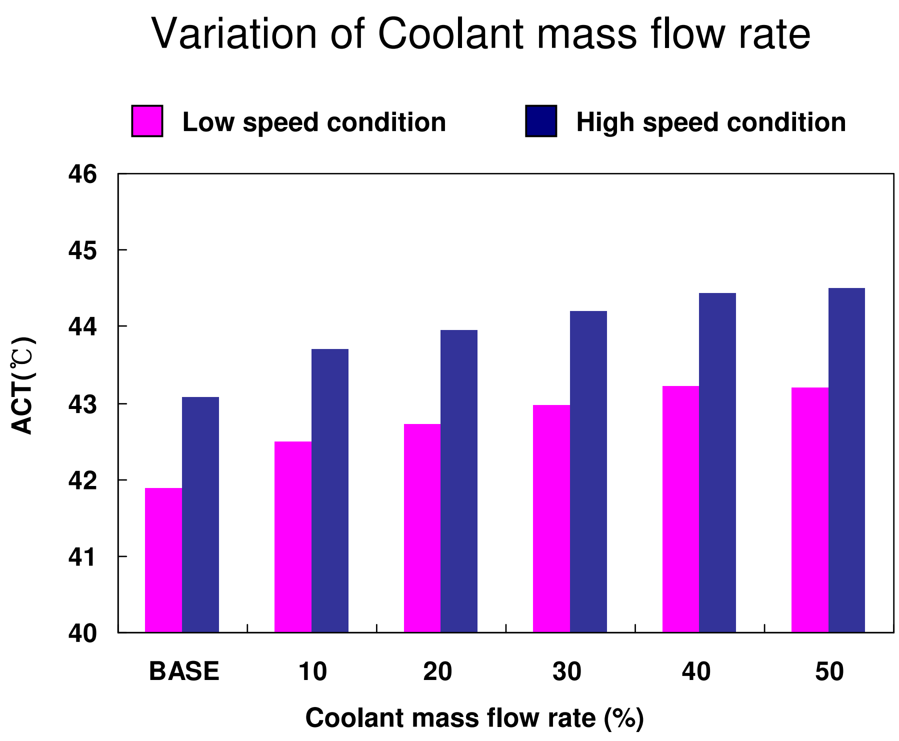
Variation of charge air mass flow rate



Variation of charge air inlet temperature

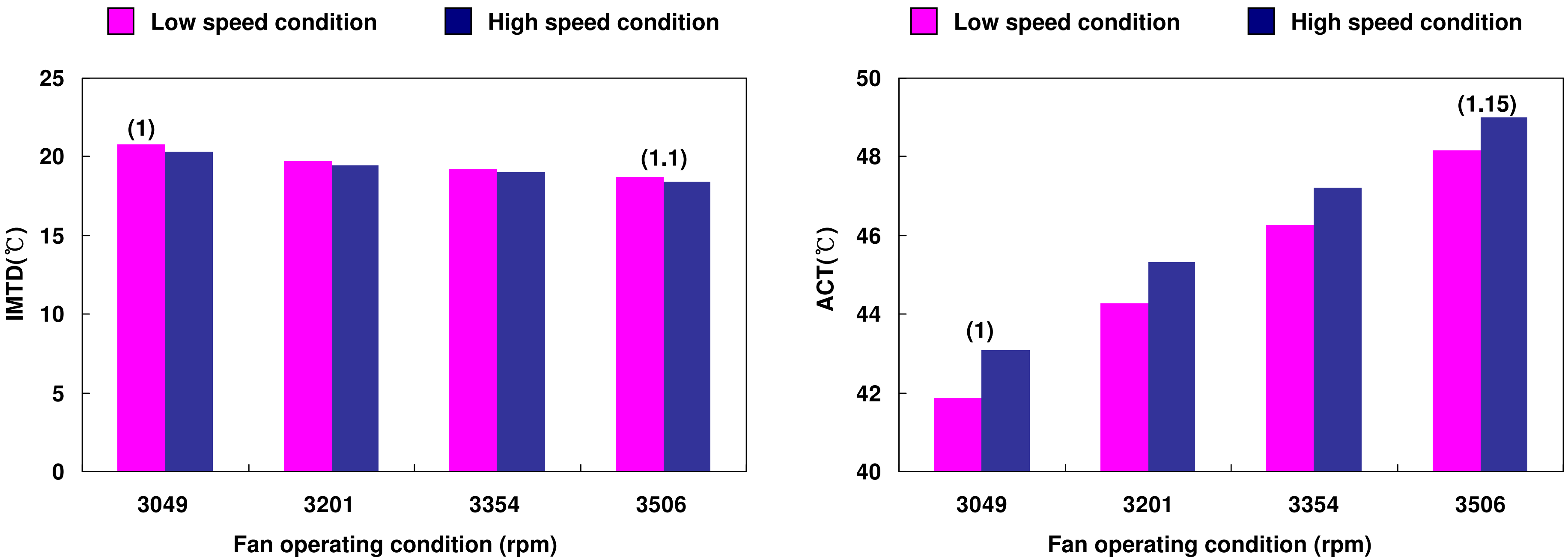


Parameter study – Radiator



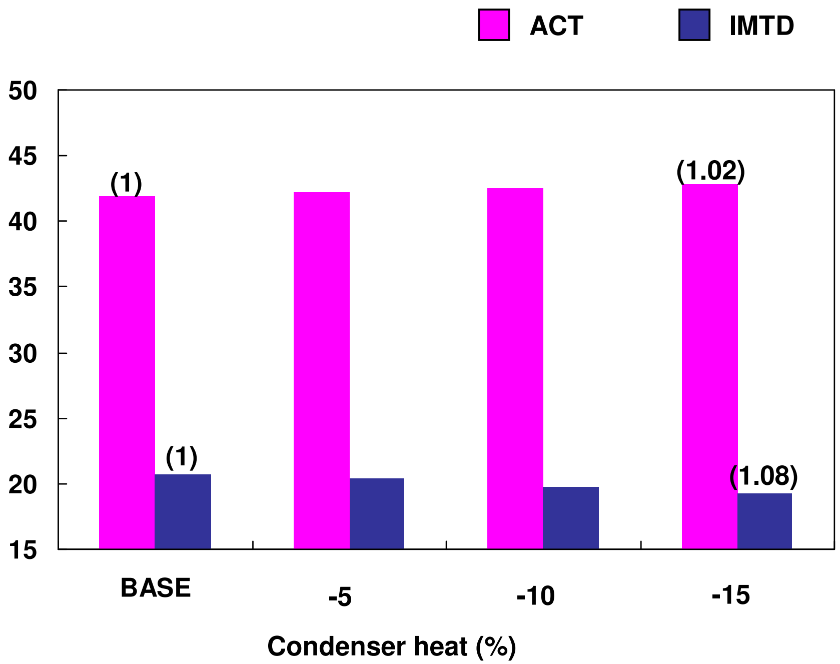
Parameter study – Cooling Fan

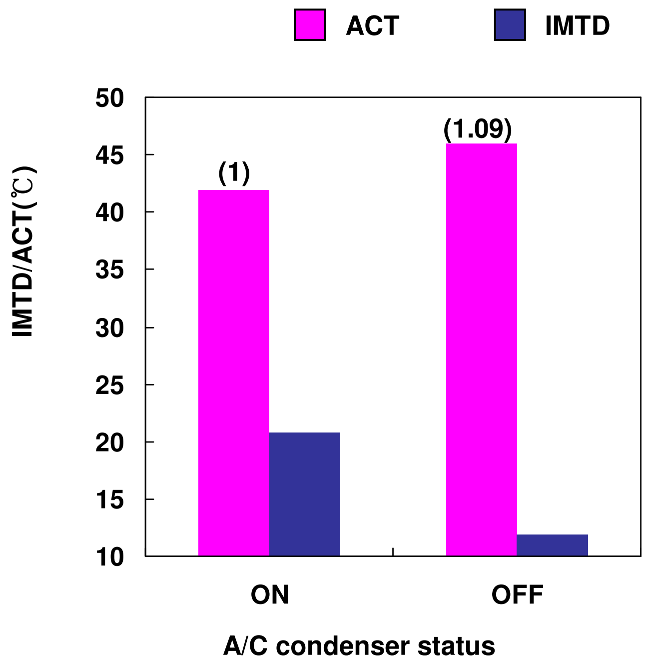
Variation of Cooling Fan Operating Speed



Parameter study – Condenser

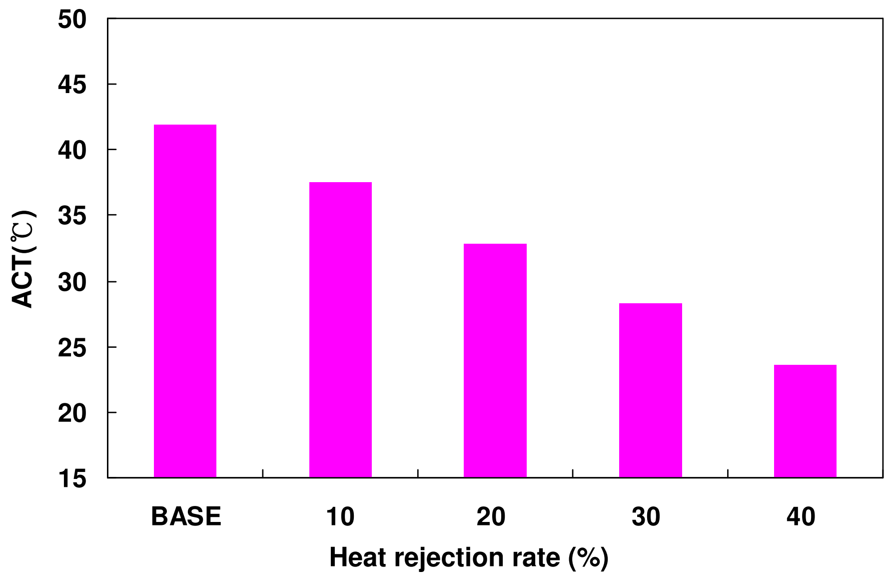
Variation of Condenser Heat



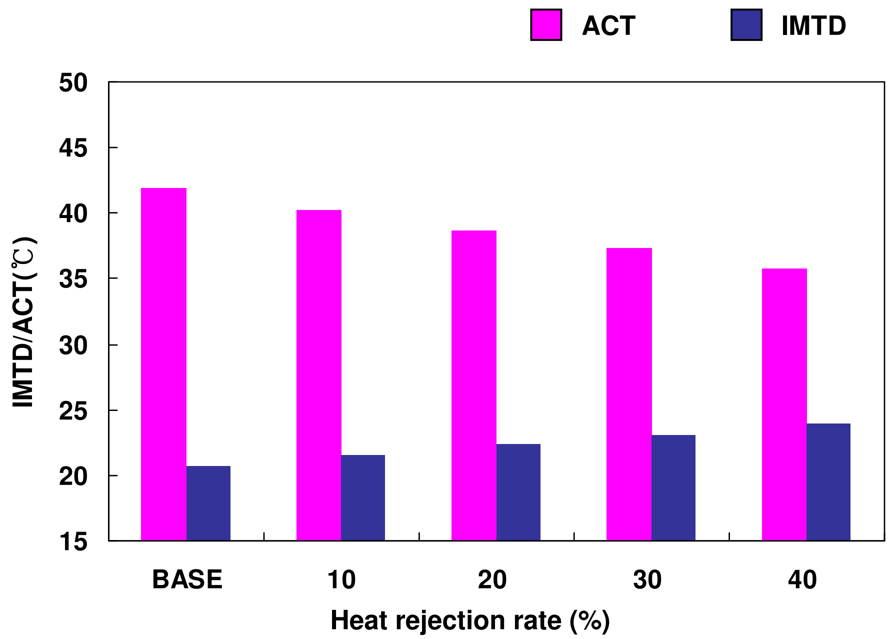


Parameter study – Heat Rejection

Variation of Heat Rejection rate (Radiator)



Variation of Heat Rejection rate (CAC)



Summary and Conclusions

- The BIR Value representing an underhood flow resistance can be obtained by correlation with a 3D simulation

- For real life application, where the mass flow is unknown, the integration of CFD is highly recommended to determine accurate predictions for mass flow and heat rejection.

- A combined simulation of 1D and 3D techniques make sense and delivers results that are highly reliable.
  - Combined simulation of thermal management with 1D and 3D tools can increase the reliability of simulation significantly.


Thank you for your attention