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Correlation of a 1D KULI model against Vehicle Test Results for an Off-Highway Vehicle

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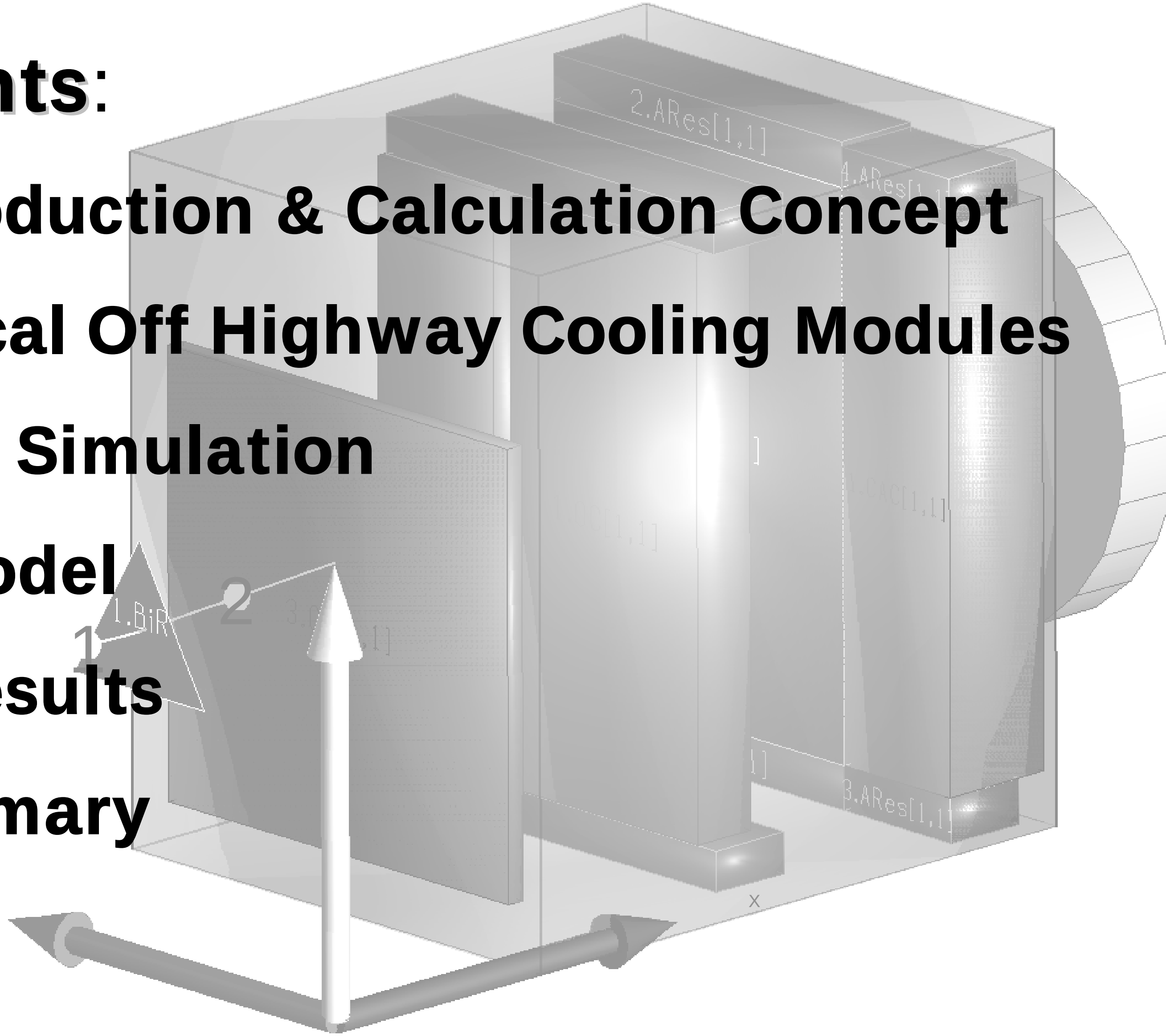
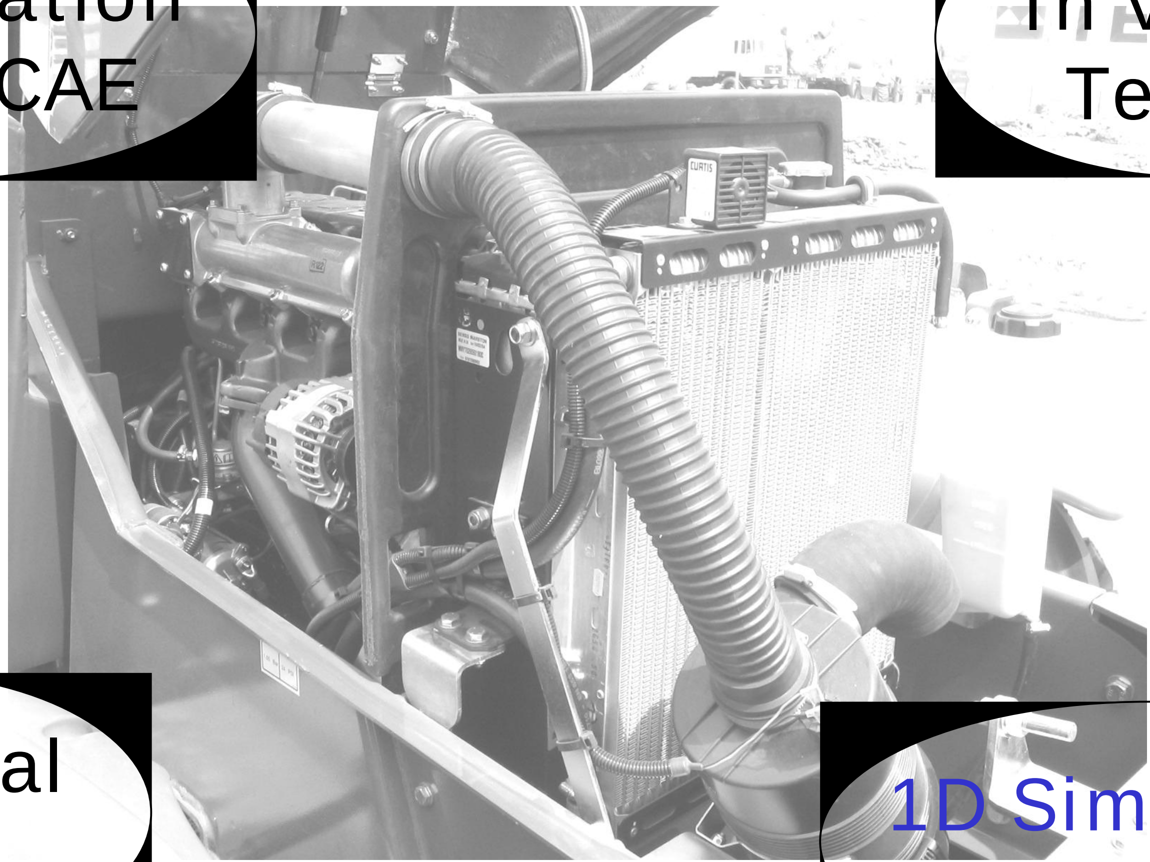


1. Introduction

- Alternative methods for determining in-vehicle performance



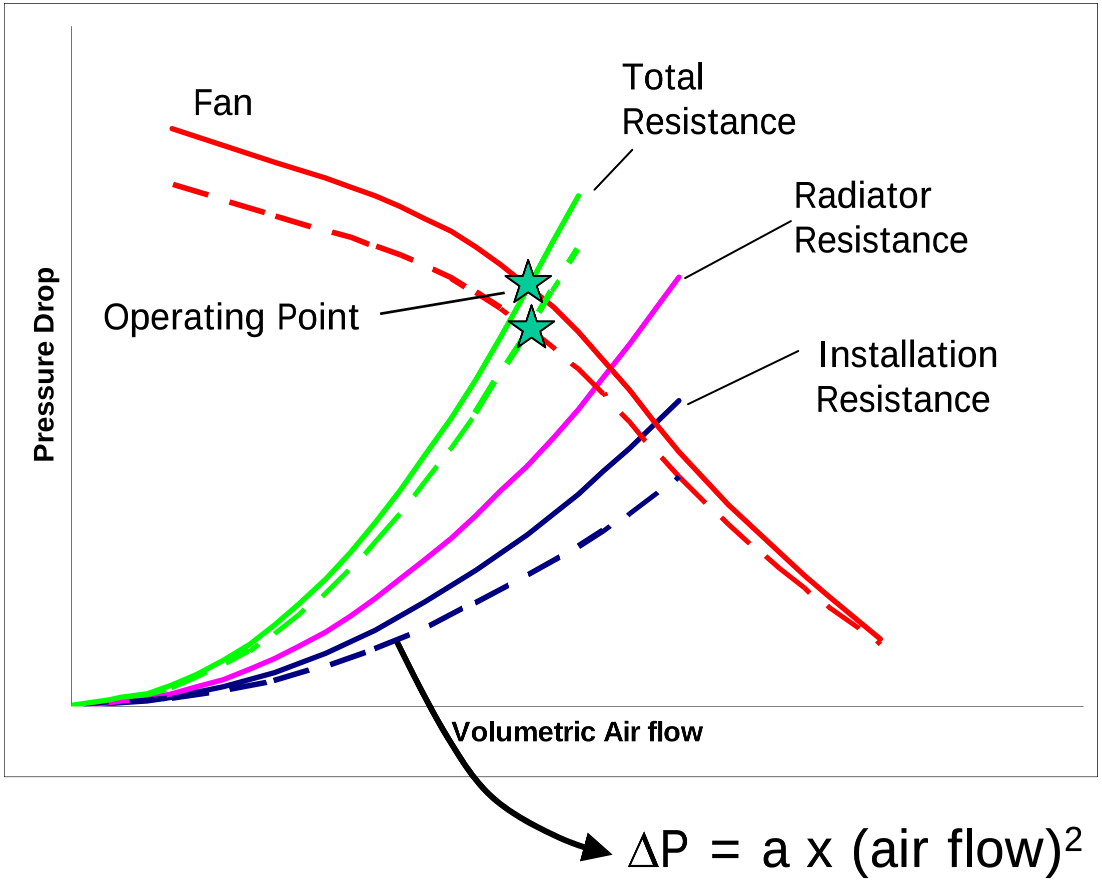
1D Thermal Simulation using KULI

Key Parameters in a KULI model:

	Typical Inner Medium Parameters	Typical Outer Medium Parameters	
Phase 1 - Calculation Data Only	Flow Rate Inlet Temperature Heat Rejection	Cooling air mass flow Air temperature Built in resistance	Calculation / estimation
Phase 2 - Prototype in-vehicle test	Flow Rate Inlet Temperature Heat Rejection	Air temperature	Measured during test
		Cooling air mass flow Built in resistance	Not measured during test

Key discussion point - correlation of KULI model to test results to determine the *Built in Resistance* (and therefore Cooling Air Mass Flow)

Calculation Concept - Operating Point of the Fan



Given data:

- Fan curve
- Radiator curve

Not known:

- Installation resistance

Note - fan data can be "free inlet/free outlet" (FIFO) or tested with a downstream restriction to simulate engine / BIR:

FIFO Fan curve

Downstream Resistance Fan curve

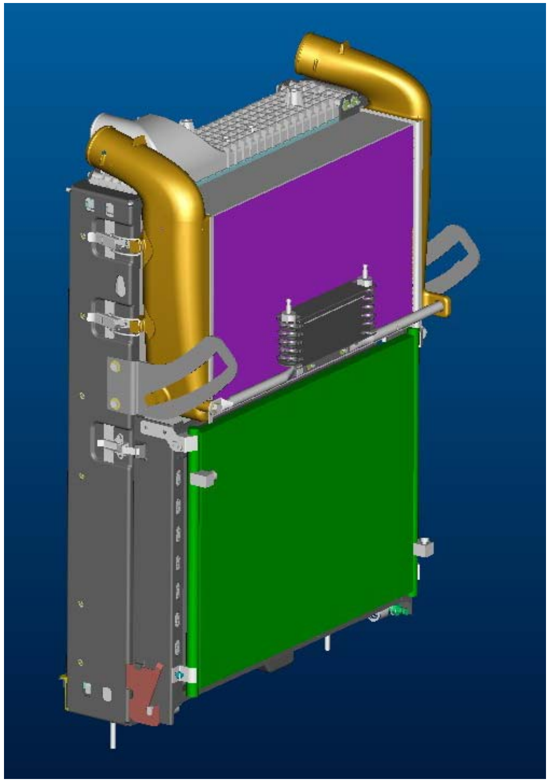
Dependant upon which data is used, KULI will require a different BIR

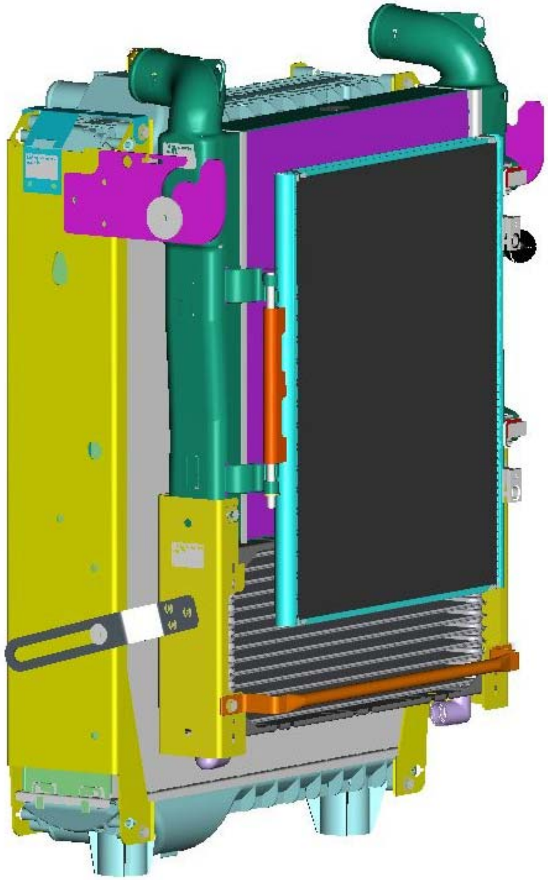
Compare different methods of finding the installation resistance :

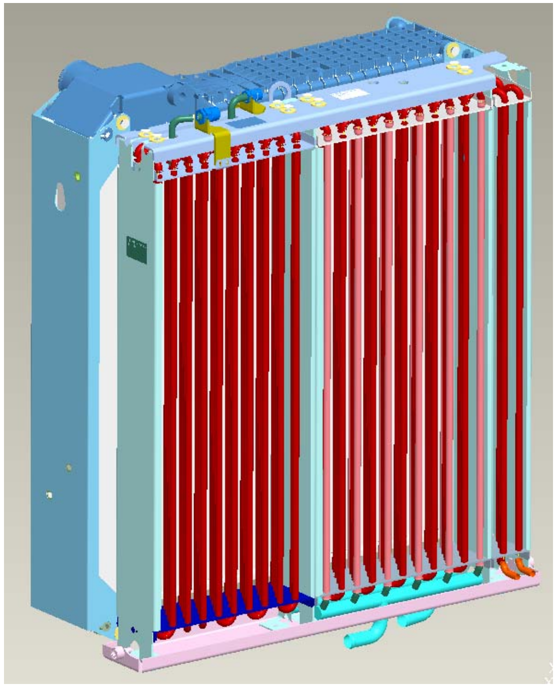
- Iterative Approach

- Using KULI advanced optimization

2. Typical Off Highway Cooling Modules:

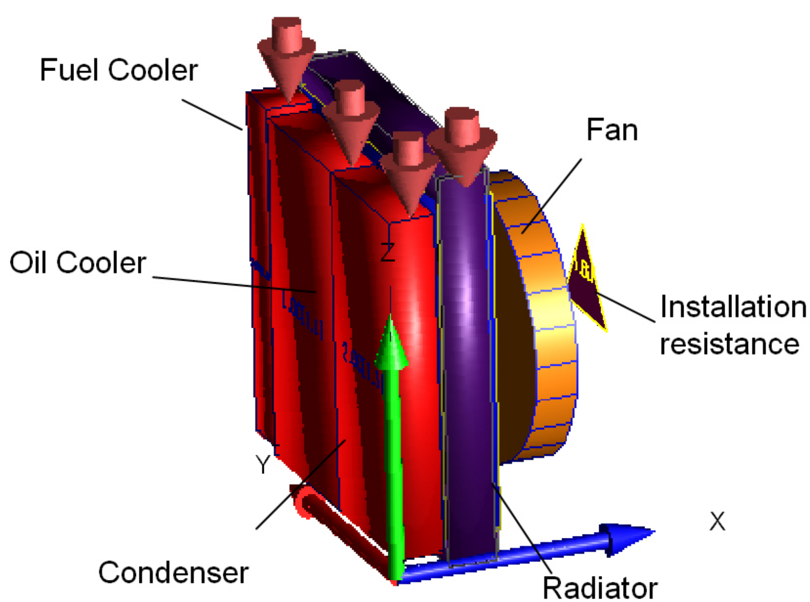


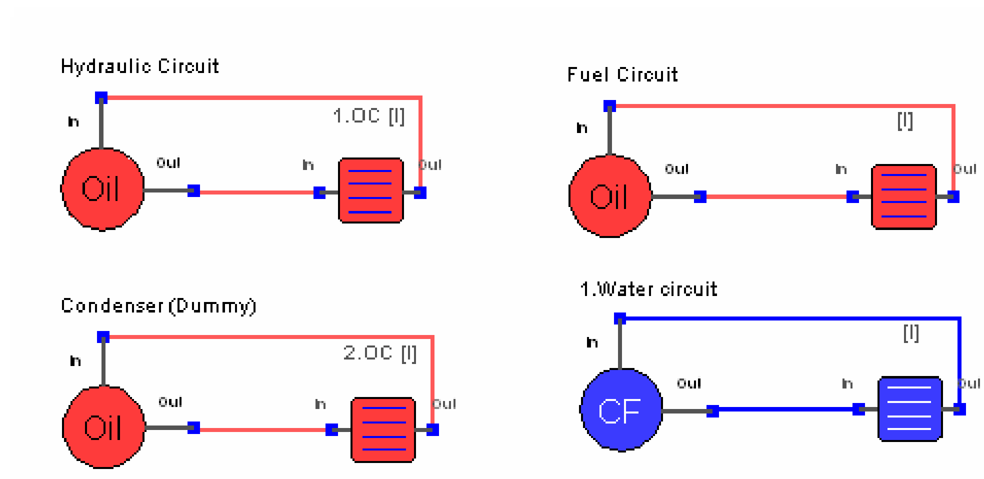




- Complex cooling modules for off highway vehicles including radiator, oil cooler (transmission and hydraulic), charge air cooler, fuel cooler and condenser
- KULI is useful for modelling complex off highway cooling modules

3. Example KULI Simulation - Compact Wheel Loader Cooling System





3D Layout

Inner Circuit

- Radiator tanks and supporting structure are modelled as an air side resistance using area resistances
- Cooling pack modelled as a block in the air path
- No CP is used since the driving speed is set to zero (cooling system at rear)
- Basic layout of Inner circuit

Test Data and Boundary Conditions

- There are four different test conditions

1. Rated speed at set load
2. 30kph Roading

} Tested on chassis dyno

3. Continuous Truck Loading
4. Intermittent truck loading

} Field tests (data taken after stabilisation of temperatures)

- For each test, data has been provided for the water, hydraulic and fuel circuits:

- Inner medium Flow rate
- Inlet Temperature
- Outlet Temperature
- Air On
- Air Off
- Ambient Temperature

Method:

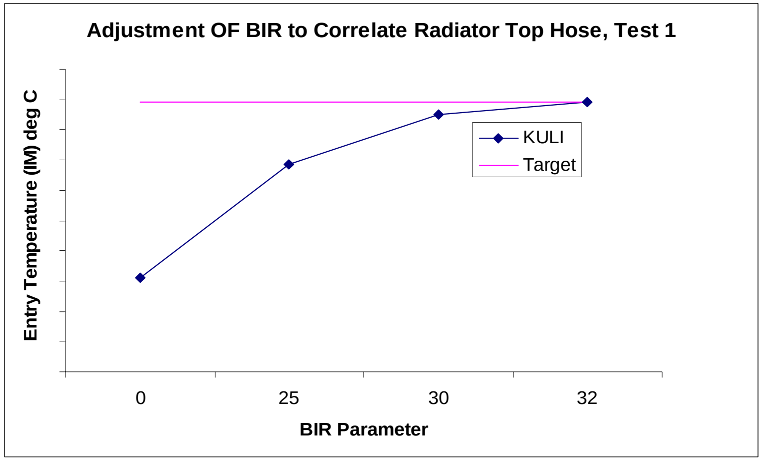
Use this data to calculate heat load:

$Q = m' \times Cp \; X \; \Delta T$

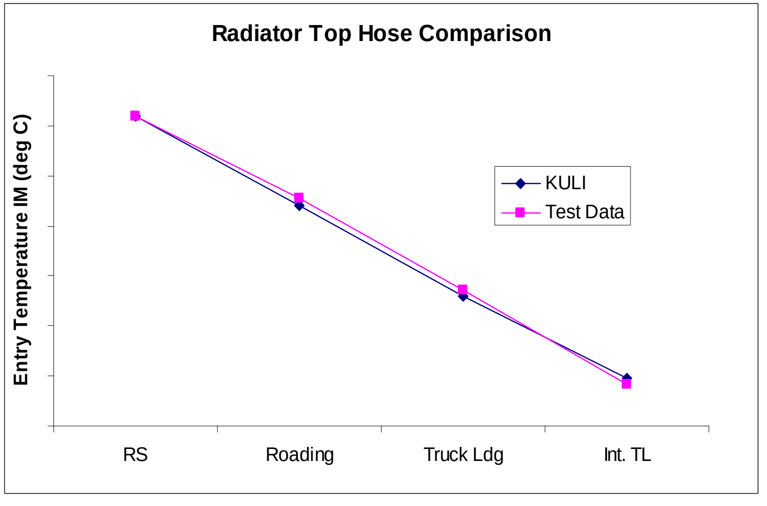
Then set as open circuit and try to balance top hose temperature with test results by varying BIR

✓ There is sufficient data to set up a KULI model

Step 1 - Calculation of BIR Parameter , Iterative Method



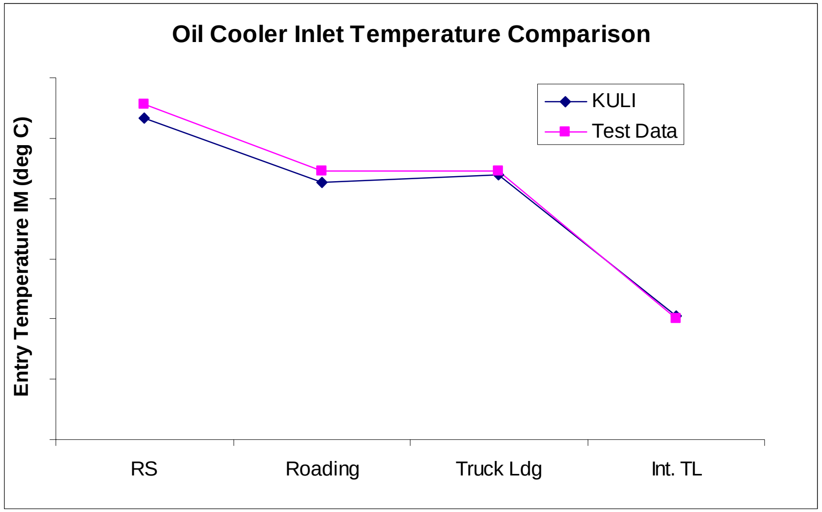
1. Iterative approach used to calculate BIR parameter and correlate model to Radiator Entry Temperature.
BIR characteristic curve is
$\Delta P = a \times (\text{air flow})^2$



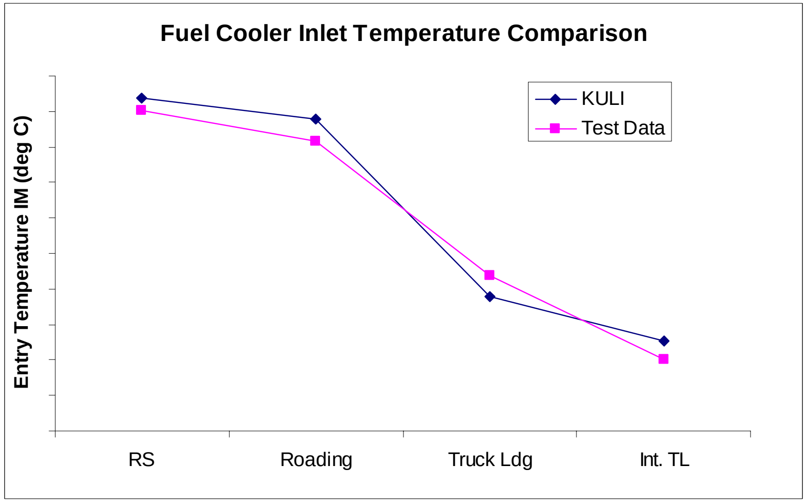
2. Run KULI simulation for all four test conditions.

Max. deviation from test result on radiator top hose is 1.6°C

Calculation of BIR Parameter by Iterative Approach - cont.



- Max. deviation of oil cooler inlet temperature from test results is 2.3^{o}C

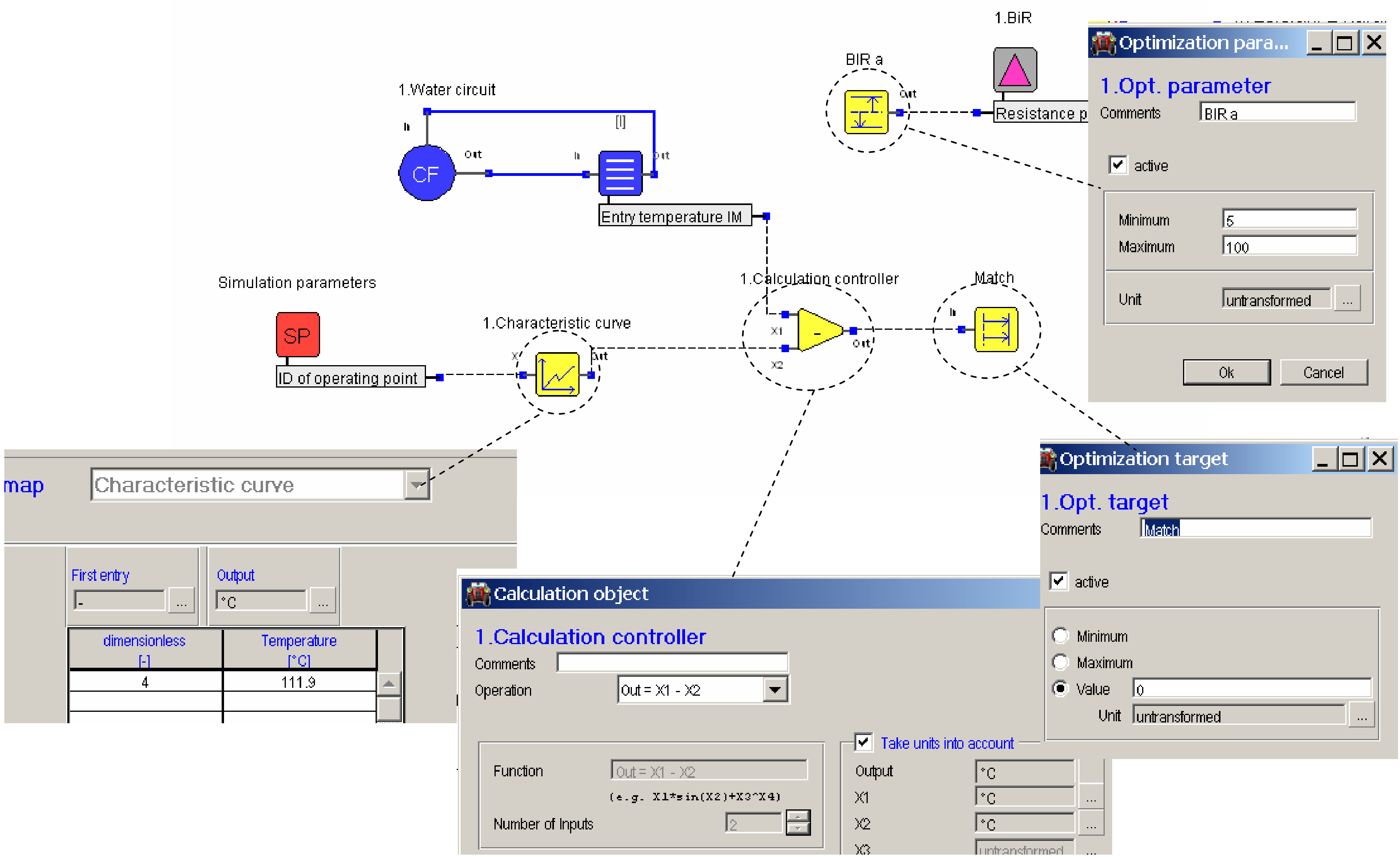


- Max. deviation of fuel cooler inlet temperature from test results is 3^{o}C (Reference only since kW is estimated).

Model correlates within acceptable limits for all circuits and tests- but how can it be improved?

Step 2 - Calculation of BIR Parameter using KULI Advanced

Inner Circuit



KULI Advanced Optimization Results

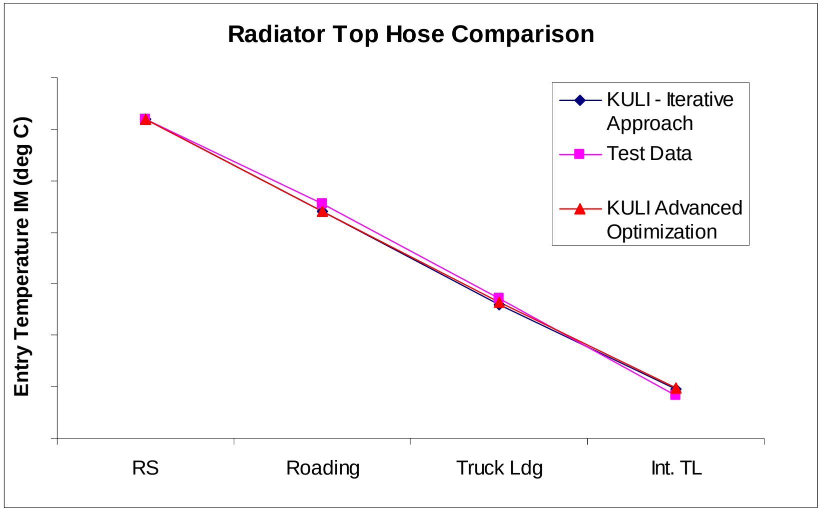
First - Comparison of BIR Optimization Parameter:

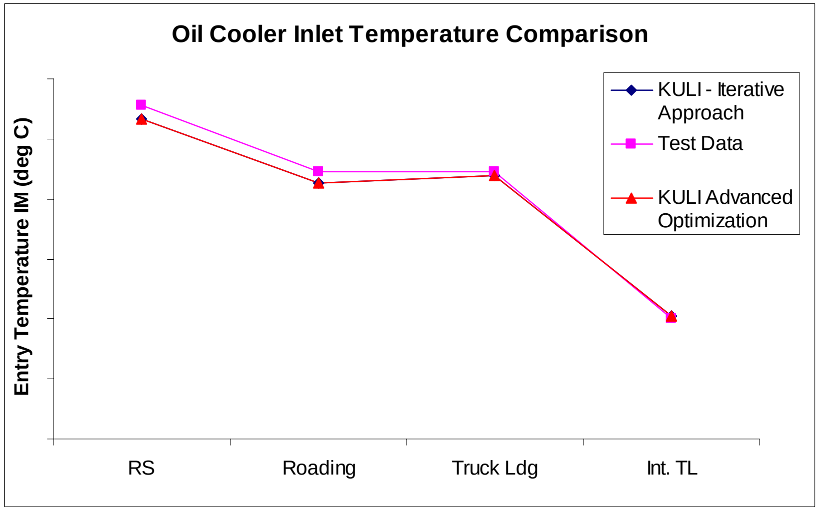
Iterative approach a = 32

KULI Optimized a = 31.8824

VERY CLOSE!

Second - Comparison of Simulation Results:





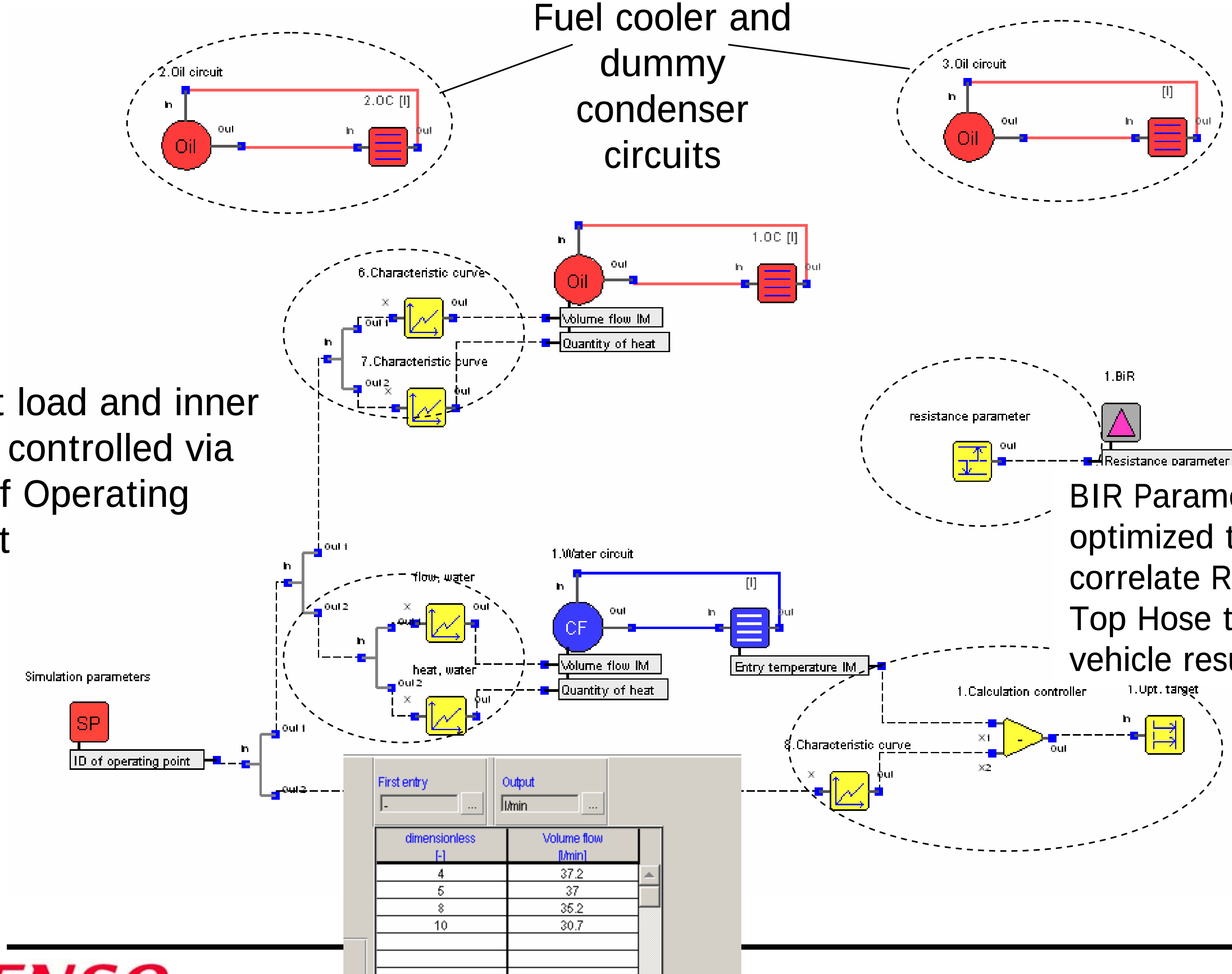
- KULI Advanced and iterative approach results very similar
- Main benefit of KULI Advanced is time saving

Final Inner Circuit - Optimization plus multiple tests

Fuel cooler and dummy condenser circuits

Heat load and inner flow controlled via ID of Operating Point

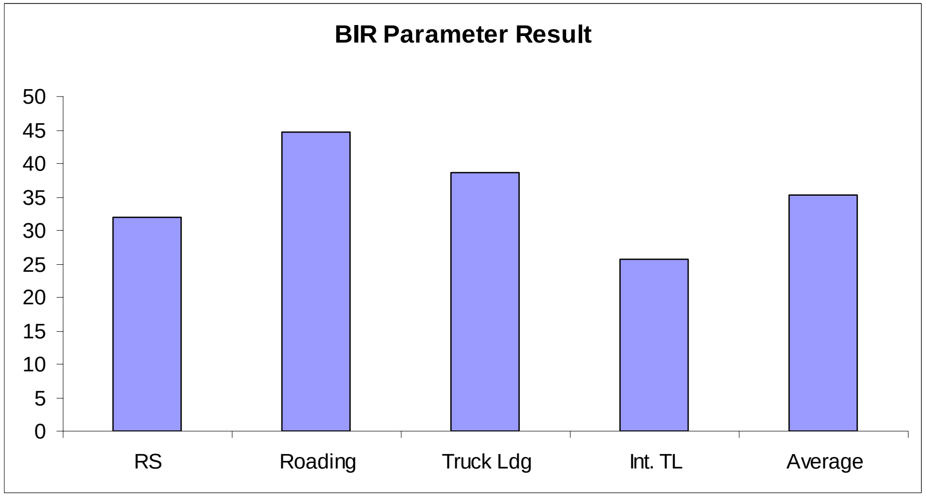
BIR Parameter optimized to correlate Radiator Top Hose to in vehicle results

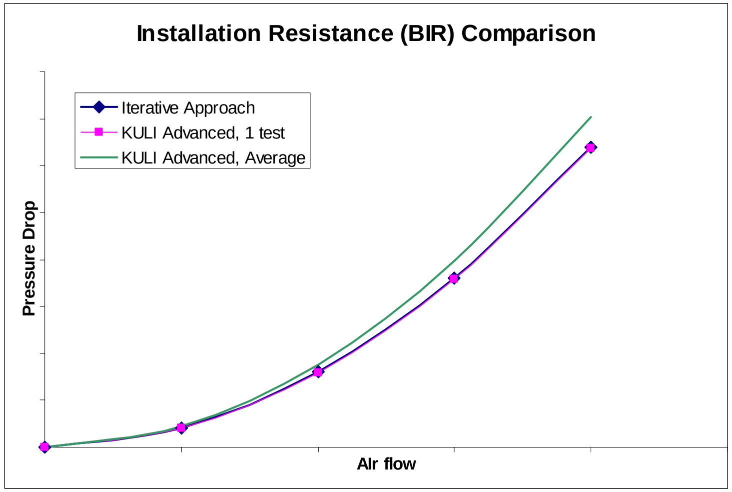


dimensionless [-]	Volume flow [l/min]
4	37.2
5	37
8	35.2
10	30.7

Step 3 - Optimization of all four test results

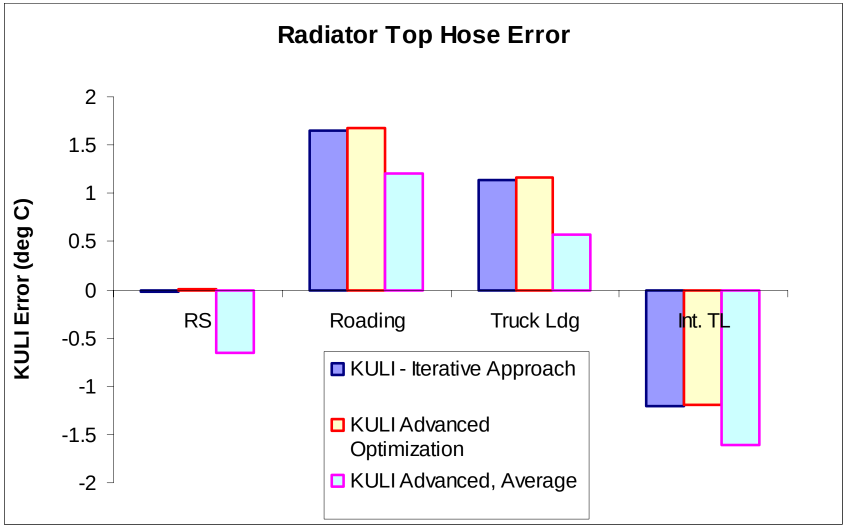
One further look at optimization - using KULI advanced to calculate the BIR parameter to optimize each individual test point

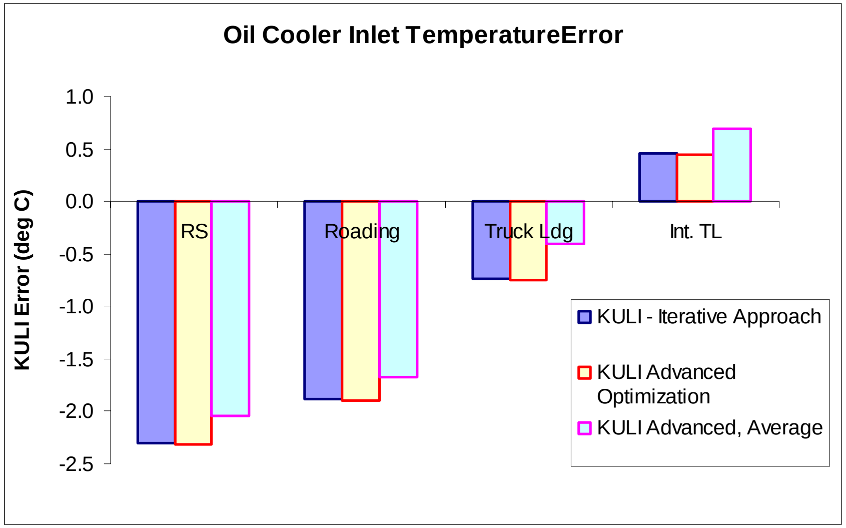




- Variation in BIR illustrates the effect of varying test conditions, measurement uncertainties , instrumentation accuracy, assumptions etc.
- By using the average BIR it possible to reduce the effect of these variables

Step 4 - Final check with the averaged BIR





Comparison of Average Errors (Absolute Values, °C):

	Iterative	KULI Advanced (1st Test only)	KULI advanced (4 tests & averaged)
Radiator	1.0	1.0	1.0
Oil Cooler	1.35	1.35	1.2

Include this BIR in your system!

Summary

1. Accuracy of model - correlation against test results

	Radiator IM Inlet Temp	Hydraulic O/C IM Inlet Temperature
Single Point Optimization (Iterative or KULI Advanced)	Good	Acceptable
Four point optimization, average result	Good	Improved (Good)

- Averaged approach has benefit on accuracy

2. Productivity (estimated time saving)

Options for optimization		Iterative (by hand)	KULI Advanced
Rad. IM Inlet Temperature	Single Point / Multi Point	100	25
Hydraulic O/C Inlet Temperature	Single Point / Multi Point	100	25

- KULI Advanced Optimization gives a major benefit of time saving

Thank you for your Attention

Any Questions?