Volvo 3P Powertrain Installation

Göteborg, Sweden

VOLVO

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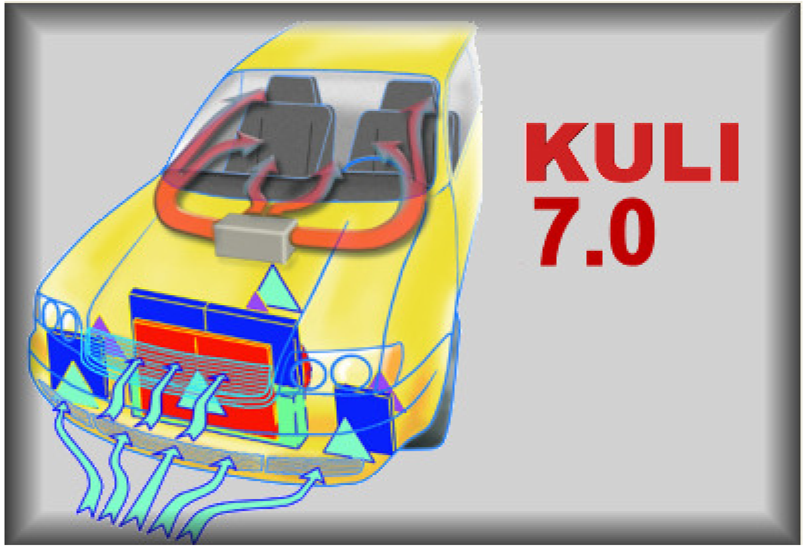
KULI Model Parameter Optimization using modeFRONTIER



modeFRONTIER
the multi-objective optimization and design environment

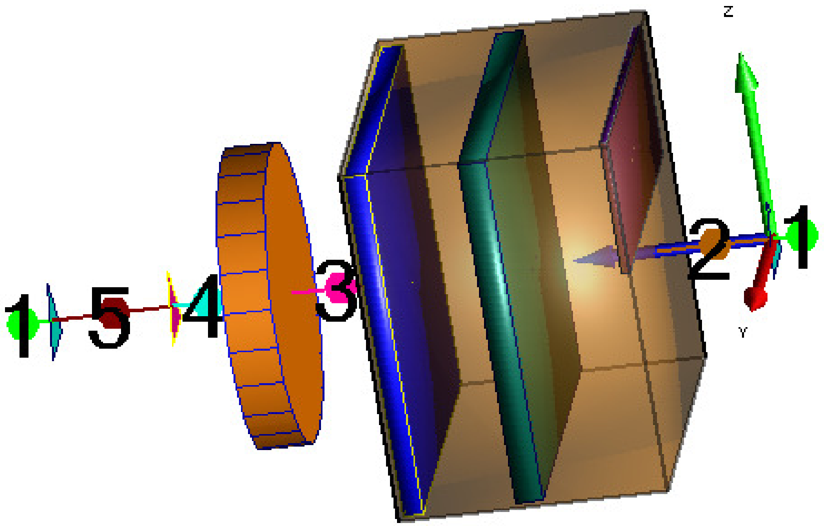
ESTECO

KULI Model Parameter Optimization using modeFRONTIER

Main Topics for Today

- Why Use this Method
- Tools and Information Needed
- Methodology Used
- Case Study & Results
- Future Plans
- Questions

Why use this Method?



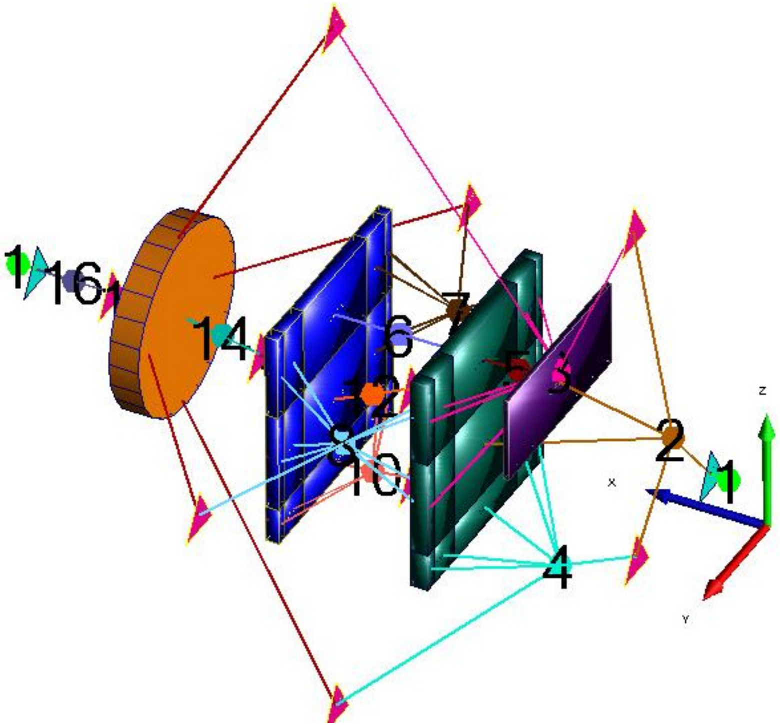
Test Data with 2 to 4 engine speeds
and a single ram air condition

Simple KULI Models with

1) Global Warm-Up for Recirculation
2) No Air By-Passing
3) Limited Test Conditions
4) Etc…

Very Limited Need for this Approach

However, to model the actual air flow conditions



Test Data with 4 engine speeds, various fan operating conditions and multiple ram air condition

More Complicated Models are needed

1) Recirculation Air Paths
2) By-Passing Air Paths
3) Increased # of Restriction Elements
4) Increase in # of Test Conditions
5) Etc…

With such a model automated optimization software provides many benefits.

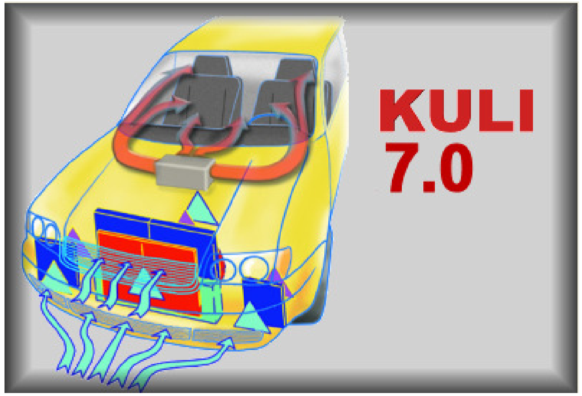
What are the benefits?

- Quickly Optimize Complex Models
- Use a Consistent Procedure
- Good Visualization tools to help with Data Analysis
- Obtain very good Correlation to Measured Results

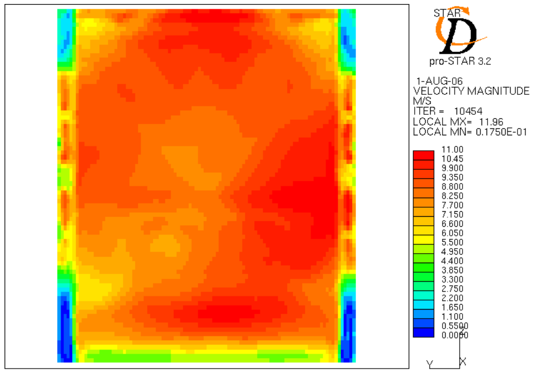
Tools and Information Needed

Software:
1) KULI
2) modeFRONTIER
3) EXCEL

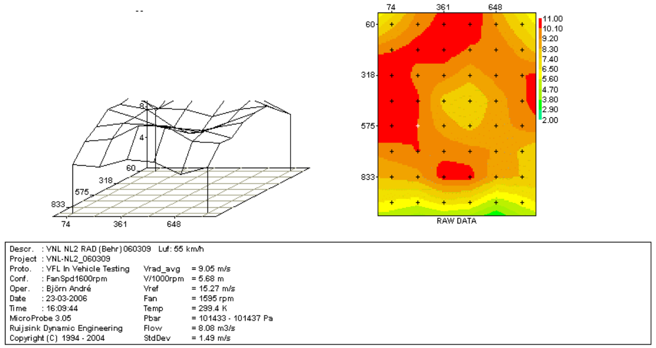
modeFRONTIER
the multi-objective optimization and design environment

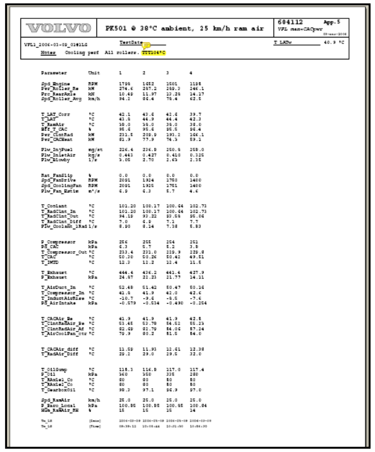


Additional Data:
1) Test Data (vehicle cooling performance)
2) Face Velocity Measurements
3) 3D CFD Results (if available)

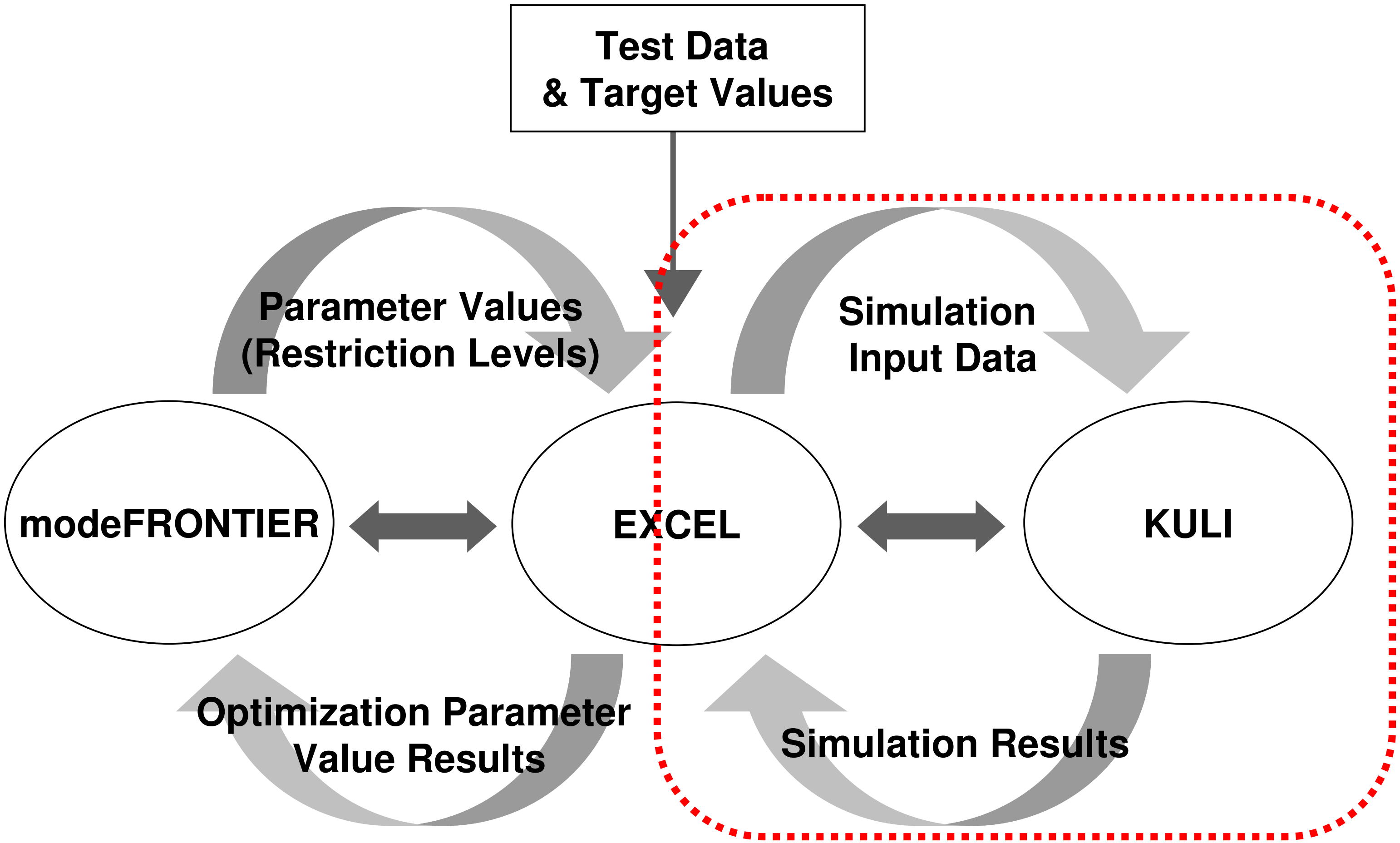


radiator front, case 2h





Methodology Used



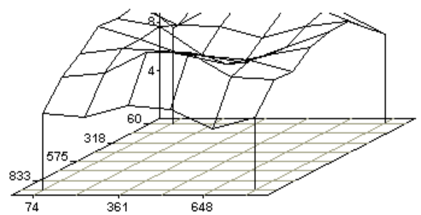
Methodology Used

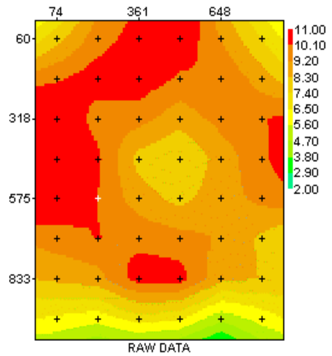
1) Develop KULI Model
2) Develop modeFRONTIER Logic
3) Build EXCEL File to run KULI using COM element interface
4) Create modeFRONTIER file to Interface with EXCEL
5) Model Optimization Steps

The two most important steps are the Development of the KULI model and the modeFRONTIER Logic

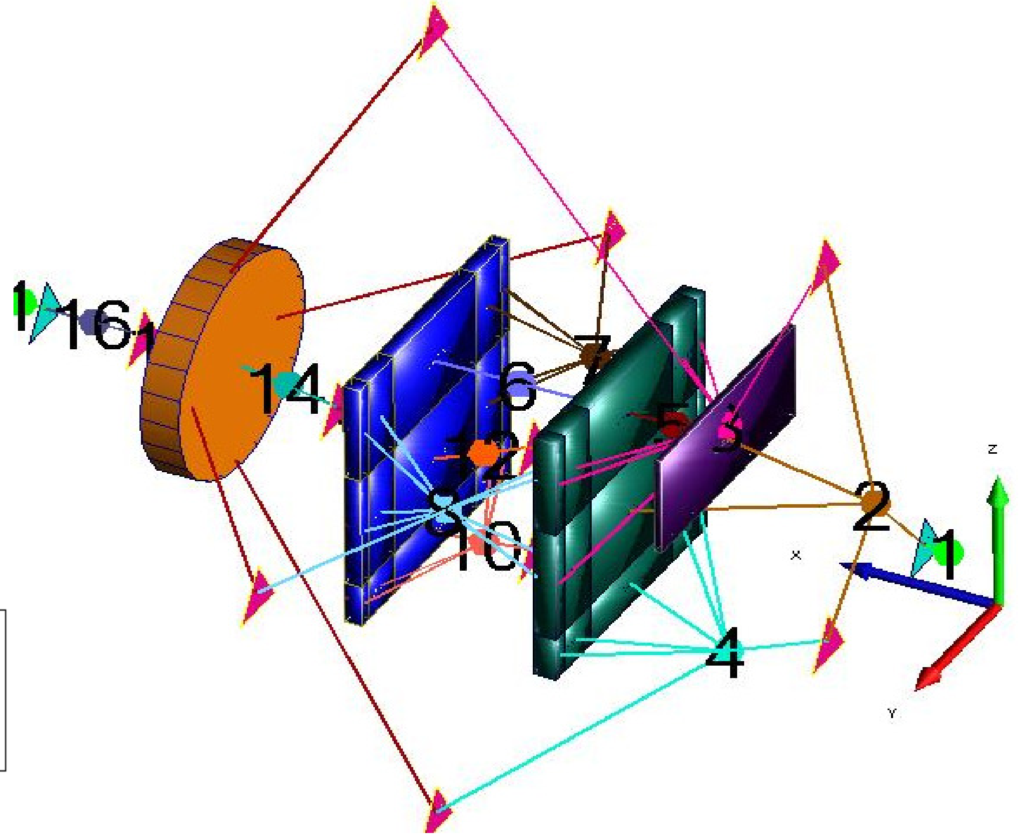
KULI Model Development

1) Use as much data as possible when developing the KULI model.
2) It is important to model the air flow paths as close as possible to reality.
3) If face velocity data is available this should be used to place restriction elements in low velocity air paths





Descr.	: VNL NL2 RAD (Behr) 060309 Luf: 55 km/h		
Project	: VNL-NL2_060309		
Proto.	: VFL In Vehicle Testing	Vrad_avg	= 9.05 m/s
Conf.	: FanSpd1600rpm	V/1000rpm	= 5.68 m
Oper.	: Björn André	Vref	= 15.27 m/s
Date	: 23-03-2006	Fan	= 1595 rpm
Time	: 16:09:44	Temp	= 299.4 K
MicroProbe 3.05		Pbar	= 101433 - 101437 Pa
Ruijsink Dynamic Engineering		Flow	= 8.08 m3/s
Copyright (C) 1994 - 2004		StdDev	= 1.49 m/s



KULI Model Development

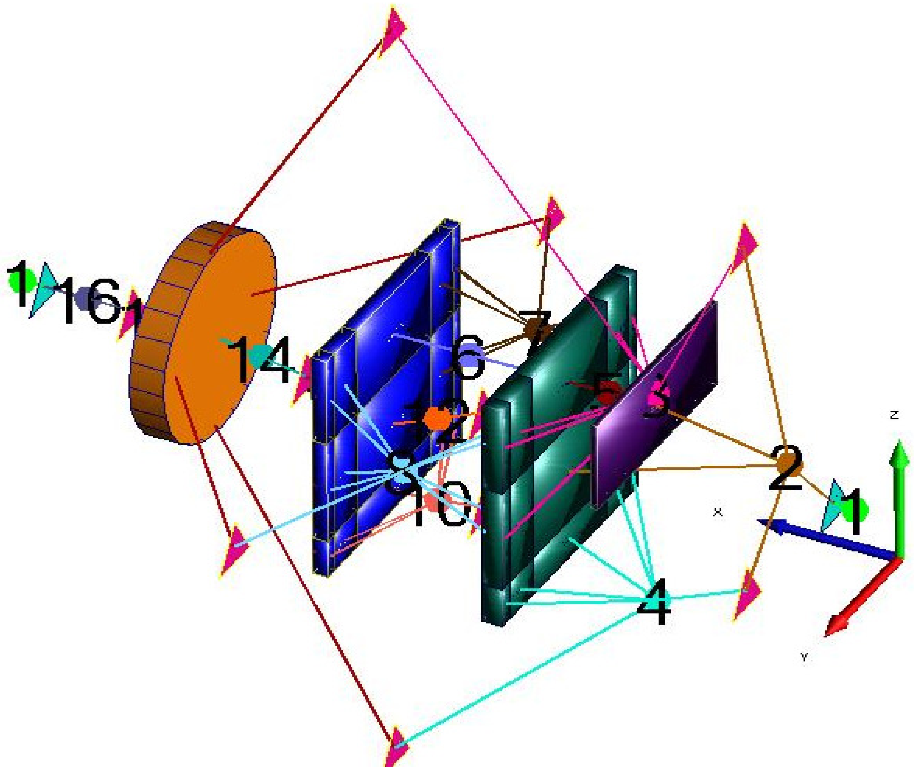
Final point to emphasis

Spend time to understand the air flow system and develop accurate air flow paths in the KULI model.

- **Finding values for the restriction elements added to the model will be the job of the optimization tool.**

modeFRONTIER Logic Development

The logic structure within modeFRONTIER defines the relationship between the input parameters and the model. Which restriction elements are independent of operating conditions and which are dependent? (i.e. Is the parameter a constant or a variable?) Also, are there levels of dependencies?



The time spent developing the KULI model will make the dependency choice easier.

modeFRONTIER Logic Development

What are you trying to optimize?

- Minimizing the total error (TT-Amb and/or IMTD)?
  - $\sum_{\text{i=1 to \# of Test Conditions}} \text{ABS}(\text{TT-Amb}_{\text{Measured}} - \text{TT-Amb}_{\text{Calculated}})$
- Minimizing the Maximum error for all operating conditions?
- Is accuracy of Radiator performance more important than CAC?
- Are certain operating conditions more important than others?
- Etc….

The answers to these questions will define the Objectives and Constraints used during the Optimization.

EXCEL File

Building the EXCEL file is a reasonably simple process. COM elements and Visual Basic programming which is common for EXCEL / KULI interfacing.

modeFRONTIER to EXCEL

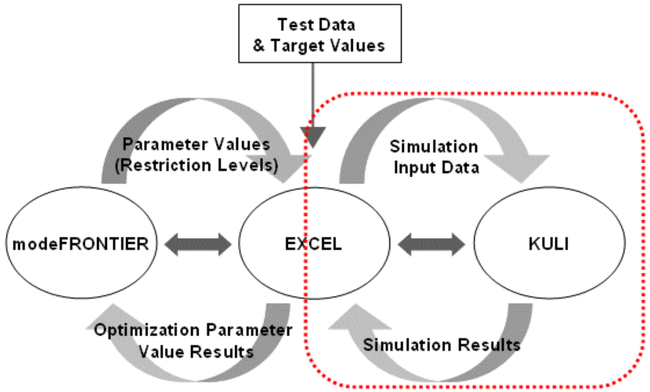
Programming modeFRONTIER is a reasonably easy task. The software is icon based with drop down menus and EXCEL is a standard interface menu option.

Optimization Steps

The optimization process generally involve reducing the "size" of the problem.

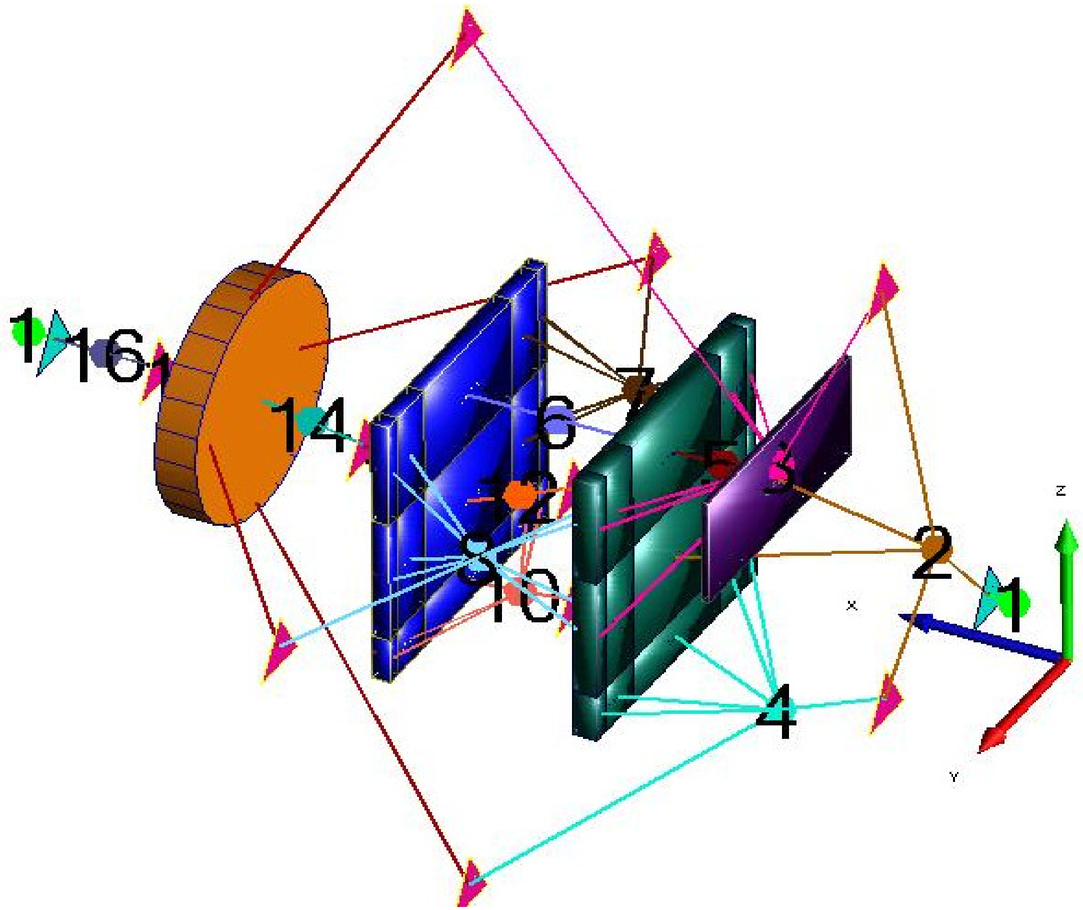
The steps include:

1. Start with wide ranges for the Parameter Values
2. Run the analysis for at least 4 to 6 generations of solutions (review for convergence)
3. Review results and adjust Parameter settings
4. Run the analysis for 10 to 20 generations
5. Review results and adjust parameter settings, modify optimization targets and add constrains
6. Run the analysis for additional generations
7. Review and check results.



Case Study

For this example the KULI model to be optimized is shown below:



Independent Variables

- **Recirculation Elements**
- **By-Pass Elements**
- **Underhood Element**

Dependent Variables

- **Fan Hub Element**
- **Lower Radiator Element**
- **Shroud Element**

Case Study

The test data includes a total of 20 different operating conditions. (4 engine speeds with fan fully engaged & 1 engine speed with the fan disengaged and 4 ram air speeds.)

The optimization target was to minimize the sum of the error values for TT-Amb. and IMTD (for all test conditions) AND minimize the maximum single point error for TT-Amb and IMTD (for all test conditions).

$\sum_{\text{i=1 to \# of Test Conditions}} \text{ABS}(\text{TT-Amb}_{\text{Measured}} - \text{TT-Amb}_{\text{Calculated}})$

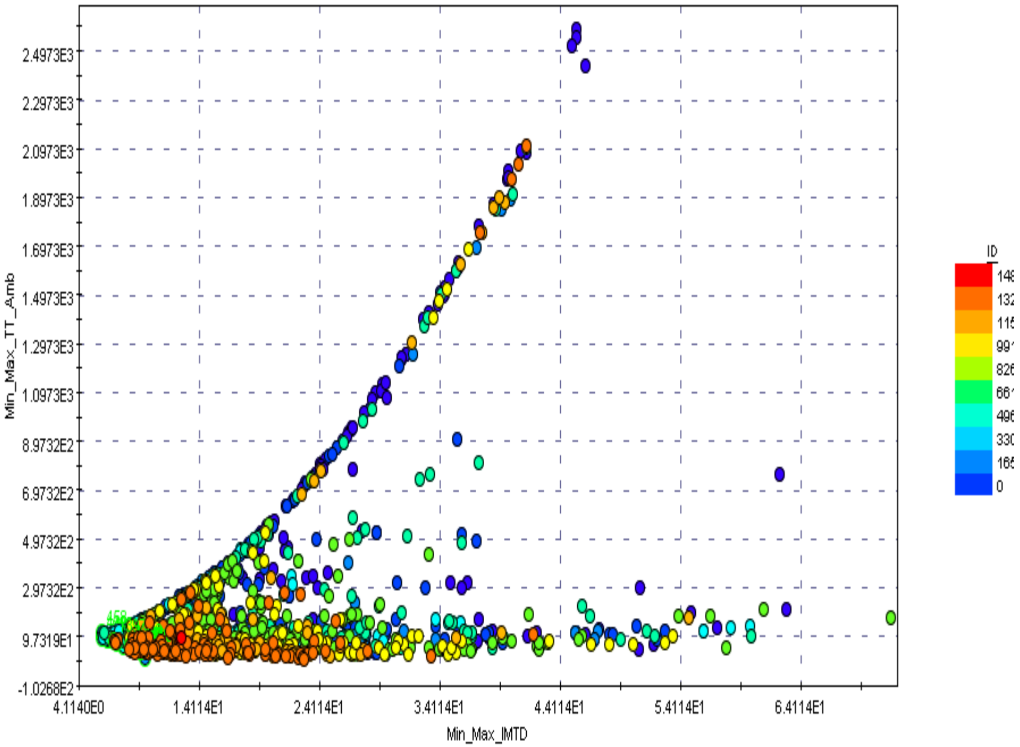
For steps 1 & 2, the optimization target was to minimize the maximum single point errors for TT-Amb and IMTD.

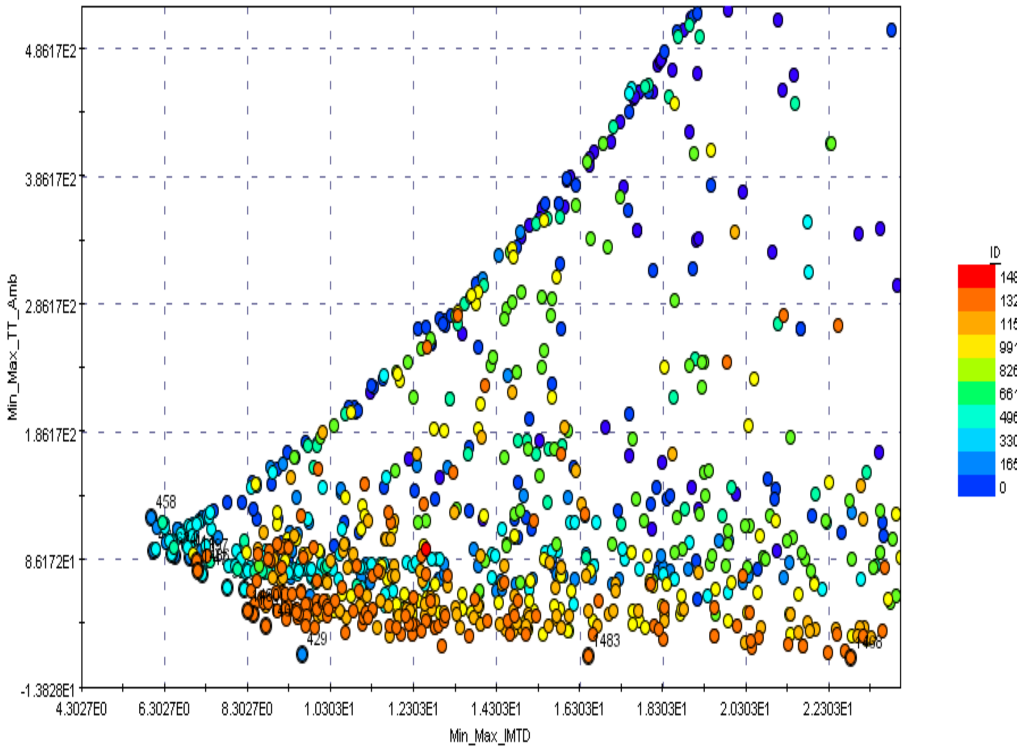
For step 3, the optimization target was to minimize the sum of the error values for TT-Amb. and IMTD & constraints were added to maintain the lowest maximum single point errors for TT-Amb and IMTD.

Case Study Results

The graphical results for the first step:

Optimization Targets - Minimize maximum single point errors for TT-Amb and IMTD



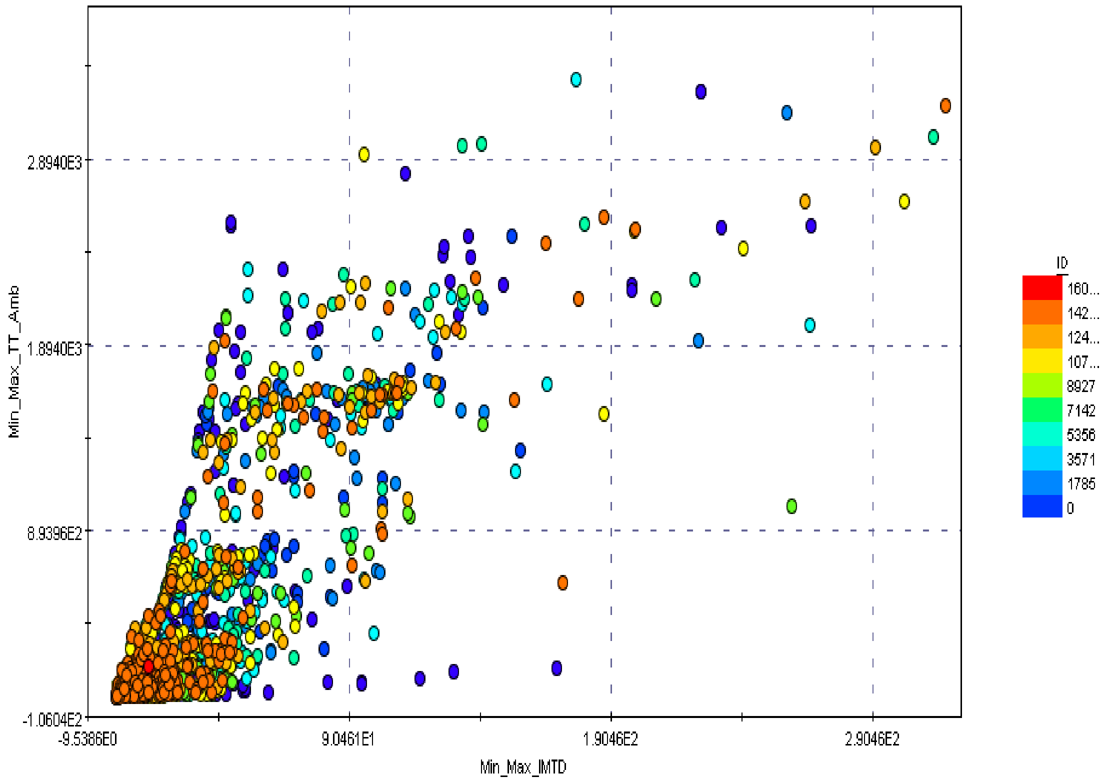


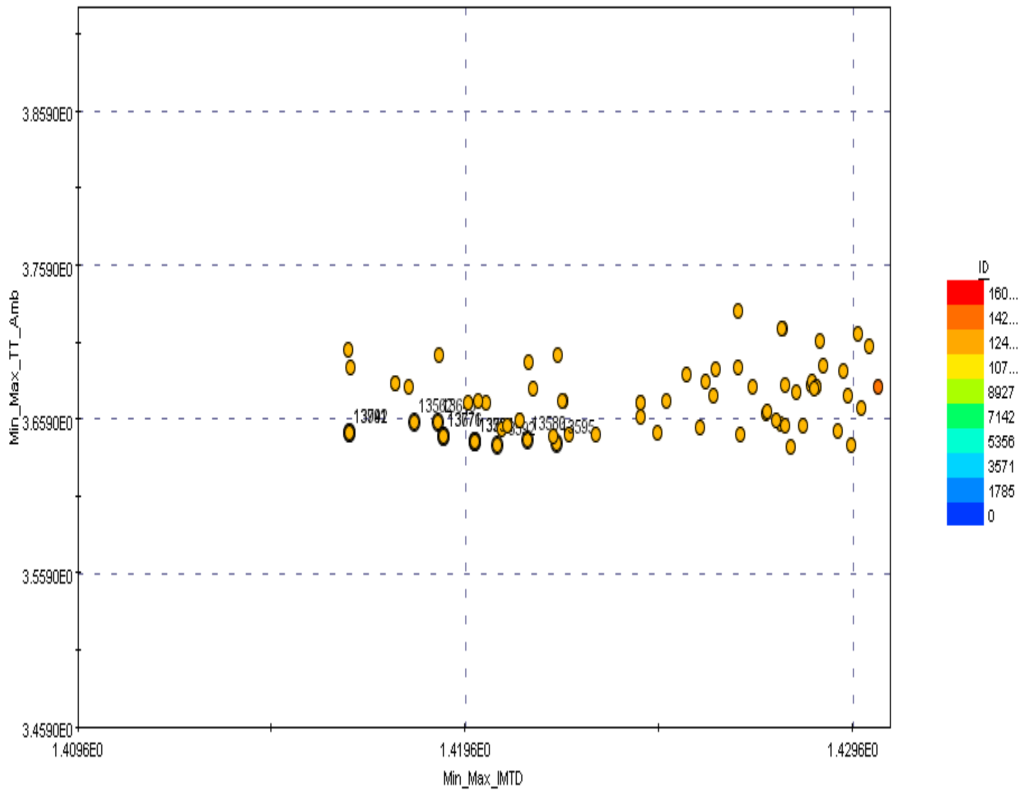
Case Study Results

The graphical results for the second step:

Optimization Targets - Minimize maximum single point errors for TT-Amb and IMTD

Parameter Values Updated

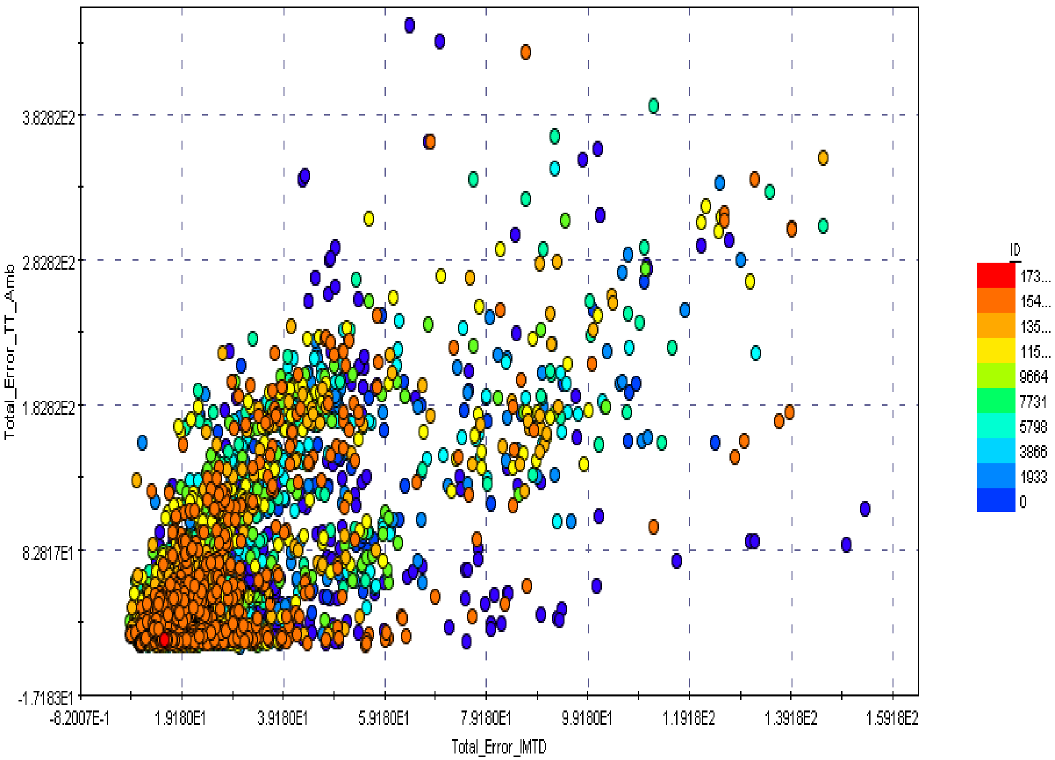


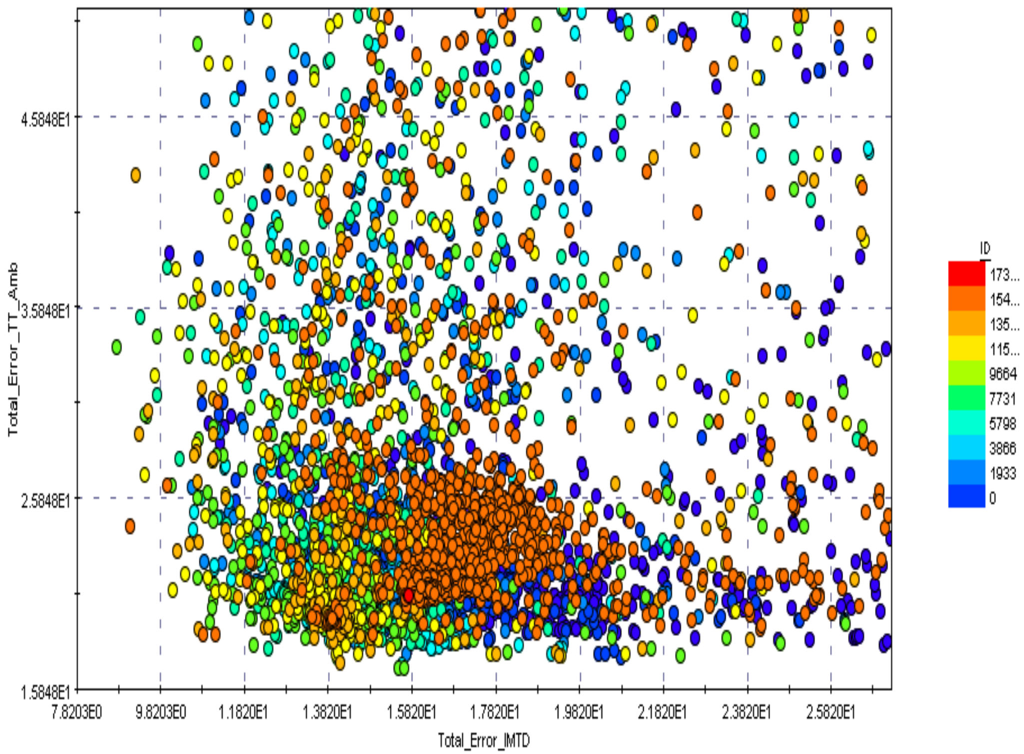


Case Study Results

The graphical results for the final step:

Optimization Target – Changed to Minimize the sum of the error values for TT-Amb and IMTD & Constraints added to maintain the low maximum single point errors for TT-Amb and IMTD





Case Study Results

The calculated cooling performance results using the parameter values for the best fit results are shown below.

Error Levels (Measured - Calculated) for Radiator & CAC Performance										
	Full Fan Engagement								Fan Disengaged	
	Engine Speeds								Engine Speed	
	1200 RPM		1500 RPM		1650 RPM		1800 RPM		1200 RPM	
Ram Air Speed	TT-Amb	IMTD	TT-Amb	IMTD	TT-Amb	IMTD	TT-Amb	IMTD	TT-Amb	IMTD
25 kph	-1.9	**1.2**	0.0	-1.0	1.0	**-1.2**	1.7	**-1.2**	0.0	0.2
55 kph	-1.9	-0.1	-0.5	-1.1	0.8	-0.6	1.9	0.0	**-2.8**	0.0
75 kph	-1.3	-0.4	1.0	-0.8	1.2	-1.2	1.8	-1.1	-0.8	-0.1
90 kph	-1.7	-0.8	-0.4	-1.2	0.7	-1.0	1.6	-1.0	1.0	-0.4

Maximum Error for Radiator Performance – 1,9 Deg K Fan On & 2,8 Deg. K Fan Off

Maximum Error for Charge Air Performance – 1,2 Deg. K Fan On & 0,4 Deg. K Fan Off

Summary

The results show that using an optimization software tool with KULI is an effective way to develop cooling prediction models.

The benefits include:
- ✓ Quickly Optimize Complex Models
- ✓ Use a Consistent Procedure
- ✓ Good visualization tools to help with data analysis
- ✓ Obtain very good Correlation to Measured Results

Future Plans

Future Activities with modeFRONTIER and KULI include:

- Developing KULI models for other vehicle installations
- Incorporating restriction matrix method for velocity distribution
- cp values and methods (Relative, Absolute & Total Pressure)
- Investigating parameter dependency levels
- Etc…

Special Thanks to:

ESTECO Nordic AB

Håkan Strandberg & Adam Thorp

KULI Group at Magna Powertrain

Thank you for your attention.

Questions?