A Novel Approach to Tractor Cooling System Design

Malay K. Kar, Ph.D.

John Deere Product Engineering Center

Waterloo, Iowa, U.S.A.

Why is this a Novel Approach ?

- Because of flow down chart similar to CTQ
- Because of use of a Statistics in the analysis
- The analysis predicts the behavior of alternatives with statistical certainty
- The analysis encompasses the interaction effects of variables

Why is this a Novel Approach?

CTQ Flow Down for Cooling System

Variables in Cooling System Simulation

3 Ys and 60 Xs

Input Independent Variables: **Macro level: X's**

1) Ambient Temperature 1

2) Heat Exchanger Geometry and Performance Data 55

a) Width
b) Height
c) Depth
d) Number of Rows of Tubes
e) Total Number of Tubes
f) Tube Cross Sectional Area
g) Wetted Perimeter of Tube
h) Direction of Internal Flow
i) Pressure Drop Vs. Internal Flow for specific entry and exit temperatures
j) Pressure Drop Vs. External Cooling Air Flow for Specific outside entry and exit temperature
k) Heat Transfer Data for conditions in i) and j) above

Why is this a Novel Approach ?

Variables in Cooling System Simulation

3) Coolant Data 3

a) **Coolant Flow Rate for Radiator**
b) Coolant Mix Ratio for Ethylene Glycol/H2O constant
c) Coolant Pressure
d) Amount of Rejected Heat
e) Type of Cooling Circuit constant

4) Fan Data 1

a) Fan OD constant
b) Number of Blades constant
c) Hub Diameter constant
d) Fan Flow Vs. Pressure Drop constant
e) Fan Power at Various RPM constant
f) Fan RPM

5) Front Grille **a) Pressure Drop Vs. Flow constant**

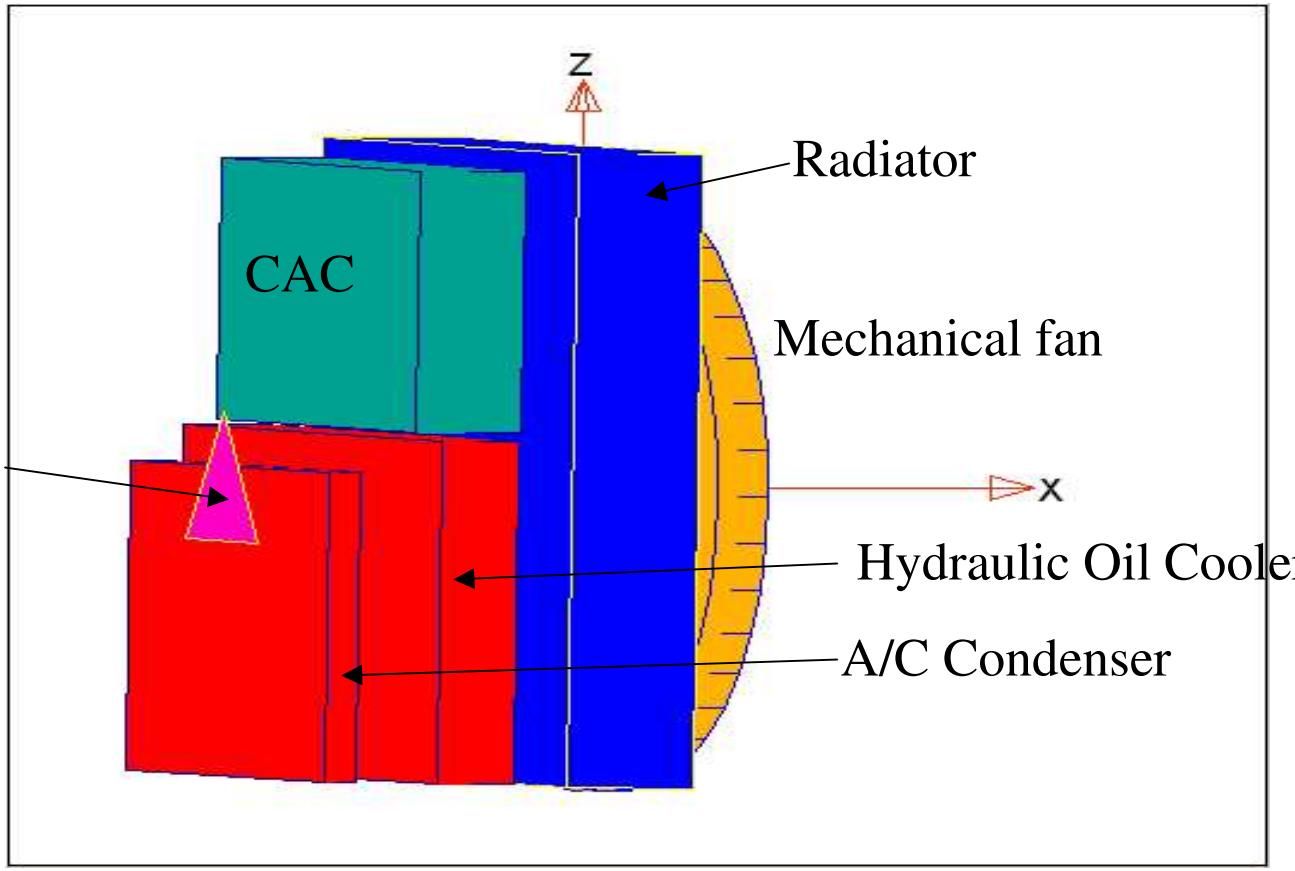
6) Engine Compartment **a) Pressure Drop Vs. Flow constant**

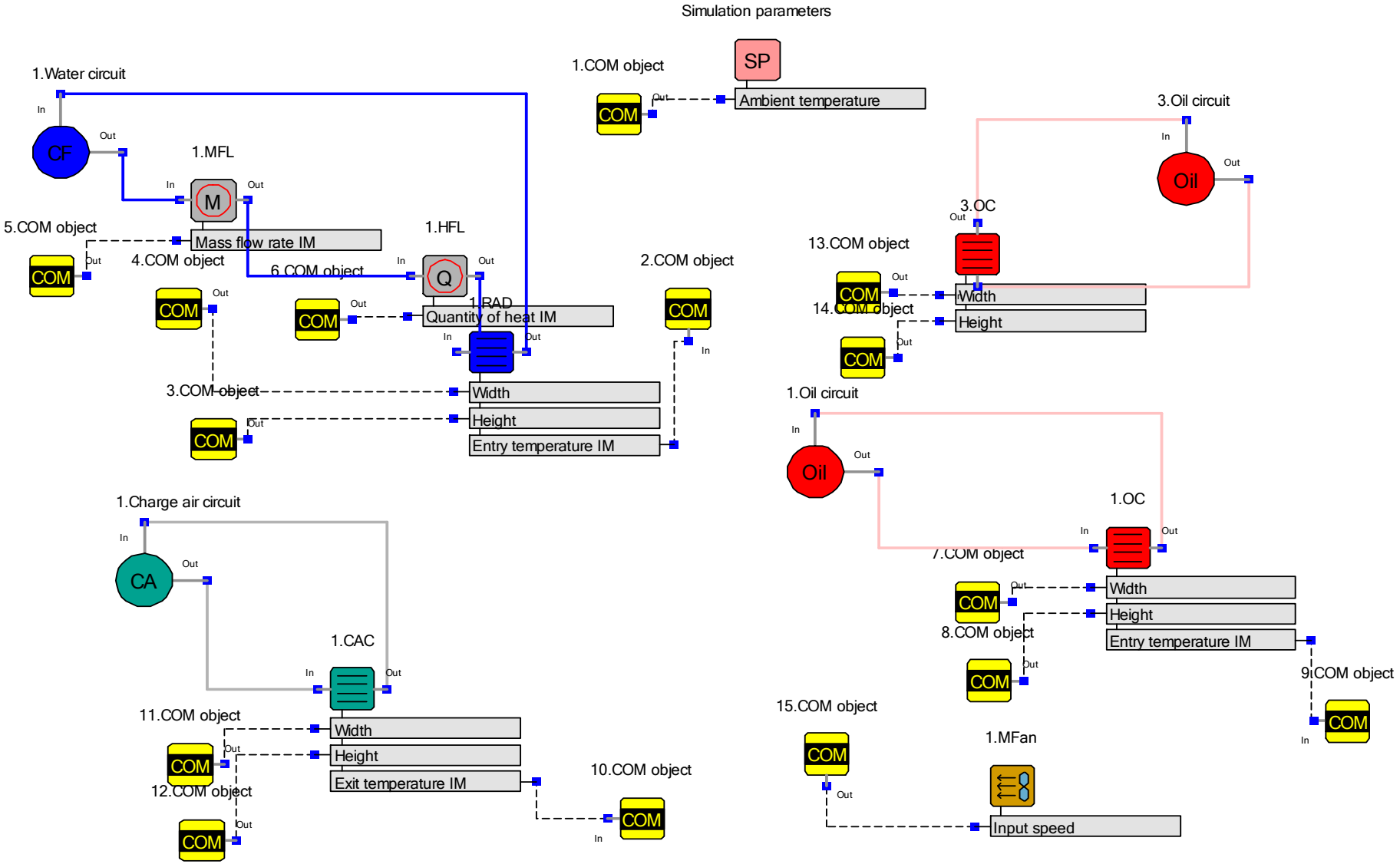
Why is this a Novel Approach ?

Critical to Quality and Dependent Variables

a) Radiator Top Tank Temperature
b) CAC Outlet Temperature
c) Transmission/Hyd Cooler Inlet Temperature

Proposed Cooling System Model for a Tractor




Simulation parameters
1.Water circuit
In
CF
Out
1.MFL
In
M
Out
5.COM object
Mass flow rate IM
COM
Out
4.COM object
COM
Out
6.COM object
1.HFL
In
Q
Out
COM
Out
1.RAD
Quantity of heat IM
In
Out
2.COM object
COM
In
3.COM object
Width
Height
Entry temperature IM
COM
Out
1.COM object
SP
COM
Out
Ambient temperature
3.Oil circuit
In
Oil
Out
3.OC
Out
13.COM object
COM
Out
Width
14.COM object
Height
COM
Out
1.Oil circuit
In
Oil
Out
1.OC
In
Out
7.COM object
COM
Out
Width
Height
Entry temperature IM
8.COM object
COM
Out
9.COM object
COM
In
1.Charge air circuit
In
CA
Out
1.CAC
In
Out
11.COM object
Width
COM
Out
Height
Exit temperature IM
12.COM object
COM
Out
10.COM object
COM
In
15.COM object
COM
Out
1.MFan
Input speed

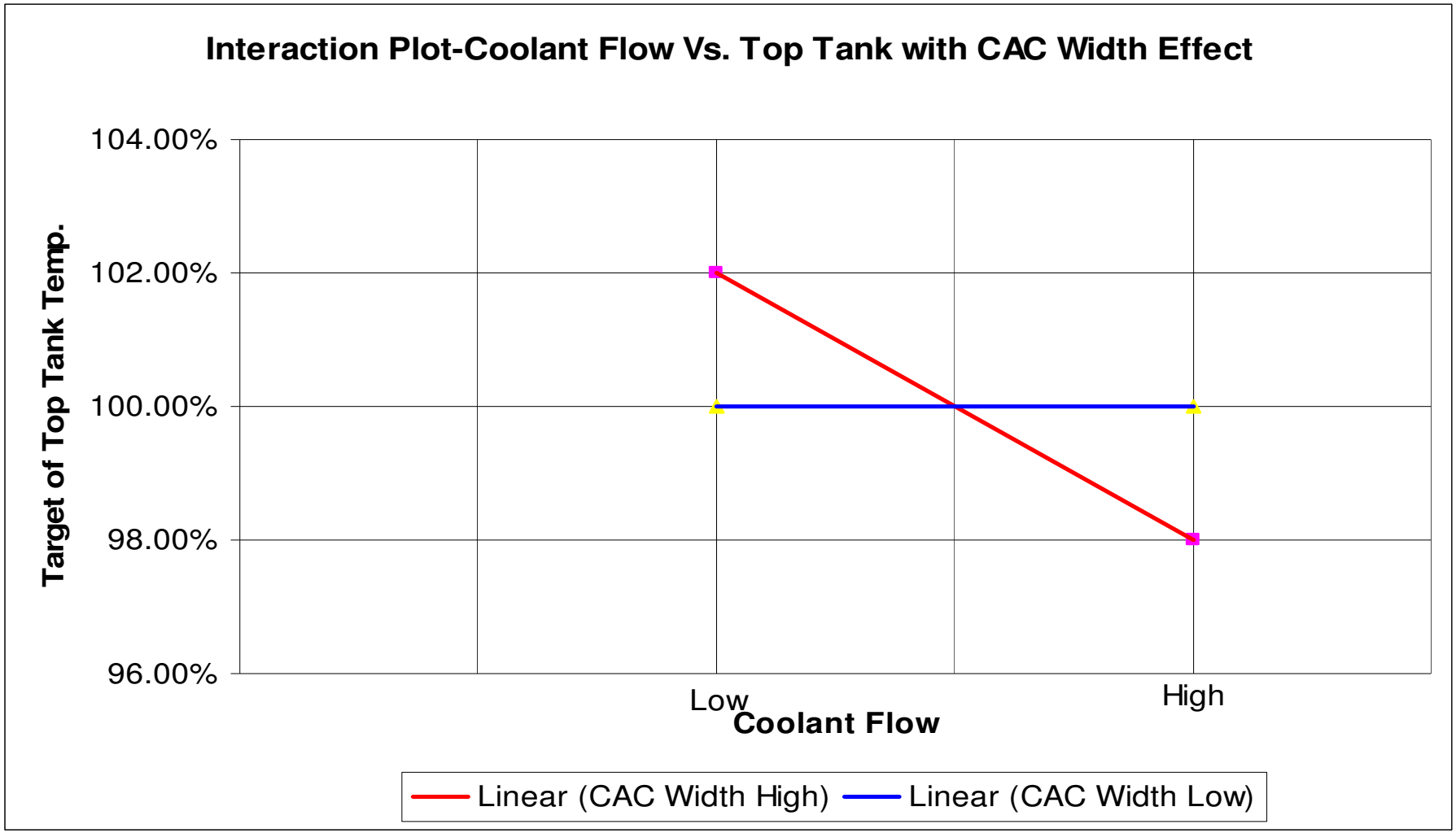
Statistical Approach

- *12 factors were used to create a matrix*
- *These are the variables that affect among others the top tank temperature, CAC outlet temperature, and the oil cooler entry temperature*
- *The variables are :*
  - *Ambient Temp*
  - *Radiator width*
  - *Radiator height*
  - *CAC width*
  - *CAC height*
  - *OC width*
  - *OC height*
  - *Condenser width*
  - *Condenser height*
  - *Coolant flow*
  - *Rejected heat*
  - *Fan speed*

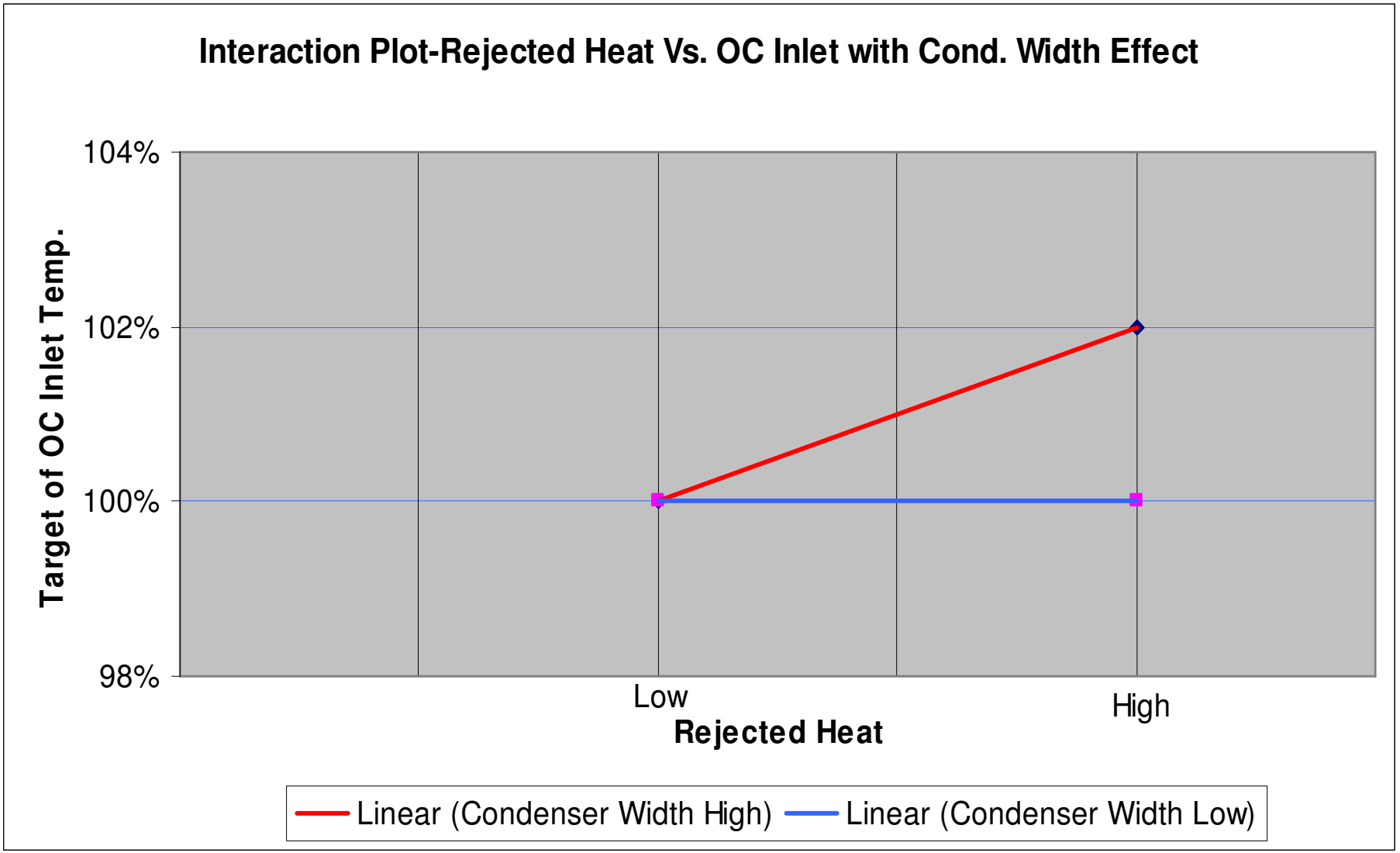
Kuli Simulation Results

A	B	C	D	E	F	G	H	I	J	K	L	M	N
KULI COM Interface for MS Excel													
						Start KULI							
KULI .scs File	C:\Kuliwork\Coolingsystems\Denso_Twintower_8630_Hotp												
	*** Change to Correct Directory												
	Amb_Temp	CAC_W	CAC_Height	Rad-Width	Rad-Height	CON-Width	CON-Heigh	OC-Width	OC-Height	Cool_Flow	Rej_Heat	Fan_Speed	CAC_Out
1	38	500	300	650	750	525	375	700	420	4.5	98	2000	64.164
2	47	500	300	650	750	600	450	820	500	6.0	157	2000	74.2918
3	38	600	300	650	750	600	450	820	420	4.5	98	2600	54.34997
4	47	600	300	650	750	525	375	700	500	6.0	157	2600	62.45888
5	38	500	400	650	750	600	375	700	500	6.0	98	2600	53.6446
6	47	500	400	650	750	525	450	820	420	4.5	157	2600	63.15209
7	38	600	400	650	750	525	450	820	500	6.0	98	2000	52.9993
8	47	600	400	650	750	600	375	700	420	4.5	157	2000	61.34613
9	38	500	300	920	750	525	450	700	500	4.5	157	2600	61.1413
10	47	500	300	920	750	600	375	820	420	6.0	98	2600	69.26817
11	38	600	300	920	750	600	375	820	500	4.5	157	2000	59.29105
12	47	600	300	920	750	525	450	700	420	6.0	98	2000	67.60897
13	38	500	400	920	750	600	450	700	420	6.0	157	2000	58.85286
14	47	500	400	920	750	525	375	820	500	4.5	98	2000	66.50224
15	38	600	400	920	750	525	375	820	420	6.0	157	2600	50.72268
16	47	600	400	920	750	600	450	700	500	4.5	98	2600	59.74366
17	38	500	300	650	857	525	375	820	420	6.0	157	2000	68.52818
18	47	500	300	650	857	600	450	700	500	4.5	98	2000	75.26311
19	38	600	300	650	857	600	450	700	420	6.0	157	2600	55.24245
20	47	600	300	650	857	525	375	820	500	4.5	98	2600	64.39265
21	38	500	400	650	857	600	375	820	500	4.5	157	2600	55.46702
22	47	500	400	650	857	525	450	700	420	6.0	98	2600	63.11494
23	38	600	400	650	857	525	450	700	500	4.5	157	2000	53.38871

Interaction Plots



Interaction Plots



CAC in Front

Detriment				Benefit		
TTT	CAC	Oil		TTT	CAC	Oil
			Fan RPM	Y	Y	Y
	Y	Y	Rad. Wid.	Y		
	Y		Oil cooler Wid.	Y	Y	Y
	Y	Y	Rad. Ht.	Y		
			Cond Ht	Y	Y	
			Oil Cooler Ht	Y	Y	Y
			CAC Wid		Y	
		Y	Cond Wid			
			Flow Rate	Y		
		Y	CAC Ht		Y	
Y	Y	Y	Amb temp			
Y		Y	Amt Rej Heat			

Benefits of Simulation and Statistical Analysis

- Cooling system modeling and Simulation are used to create a matrix without running tests in the lab
- The results from analyses help to work upfront with the supplier to create a viable design
- A very cost effective approach to design where a lot of variables interact
- The results of analysis give an insight to the interaction effects which otherwise might have been difficult to visualize

Benefits of Simulation and Statistical Analysis

- Optimization of design is possible
- Will help to reduce development time in the lab