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# Evaluation of Next Generation Military Vehicle Cooling Systems

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## Report Documentation Page

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# Outline

Unclassified

- 
- Thermal Challenges in a Military Environment
  - Traditional vs. Alternative Approach
  - Thermal Testing
  - Thermal Tool
  - Pilot Project – Applying the Simulation
  - Results
  - Next Steps

# Thermal Challenges

Unclassified

*Military needs differ from most commercial applications*

- Longer service life
- Shorter operational life
- Environmental extremes
- Worldwide operation
- Adverse operating conditions
- Both on- and off-road mission profiles
- Minimal maintenance during combat operation



# Thermal Challenges

Unclassified

## *Cooling System Design Factors*

- Severe shock & vibration
- Long term storage
- Challenging longitudinal & lateral slopes
- Corrosive battlefield atmosphere & fording
- Ground-hop capability
- Airside clogging of heat exchangers
- Ambient temperature extremes & high altitudes



# Thermal Challenges

Unclassified

*Military vehicles are facing ever increasing challenges of meeting cooling system requirements*

- Additional armor
- Power upgrades
- Extremely hot environments
- Heat loads associated with hybrids
- Adverse operating conditions



# Traditional Approach

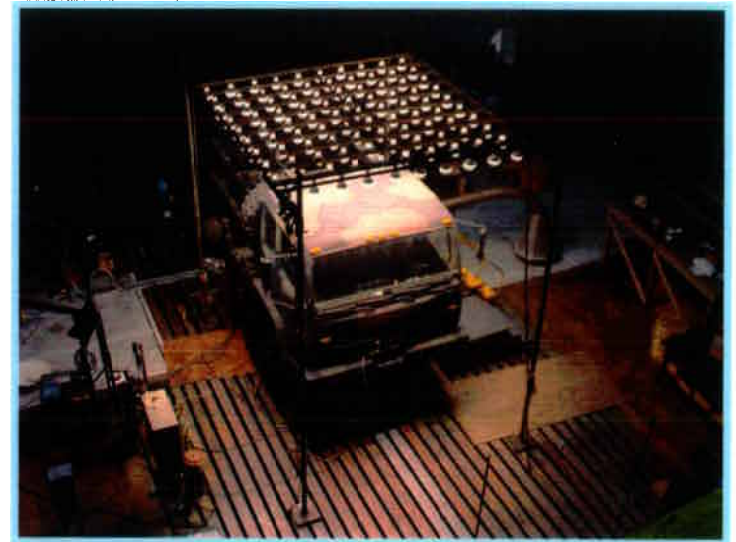
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*Meet thermal challenges through thermal testing*

- Optimize cooling system performance
- Select improved components – Radiator & Fan
- Conduct vehicle thermal testing
- Evaluate impact to cooling system



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# Alternative Approach

Unclassified

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*Share thermal challenge through an interactive technique*

- Connect vehicle level simulation with vehicle test
- Link 1D simulations to testing process
  - Evaluate multiple vehicle variants/configurations
  - Accomplish rapid optimization of thermal system
  - Identify best candidates to test
  - Achieve thermal goals

# Alternative Approach

Unclassified

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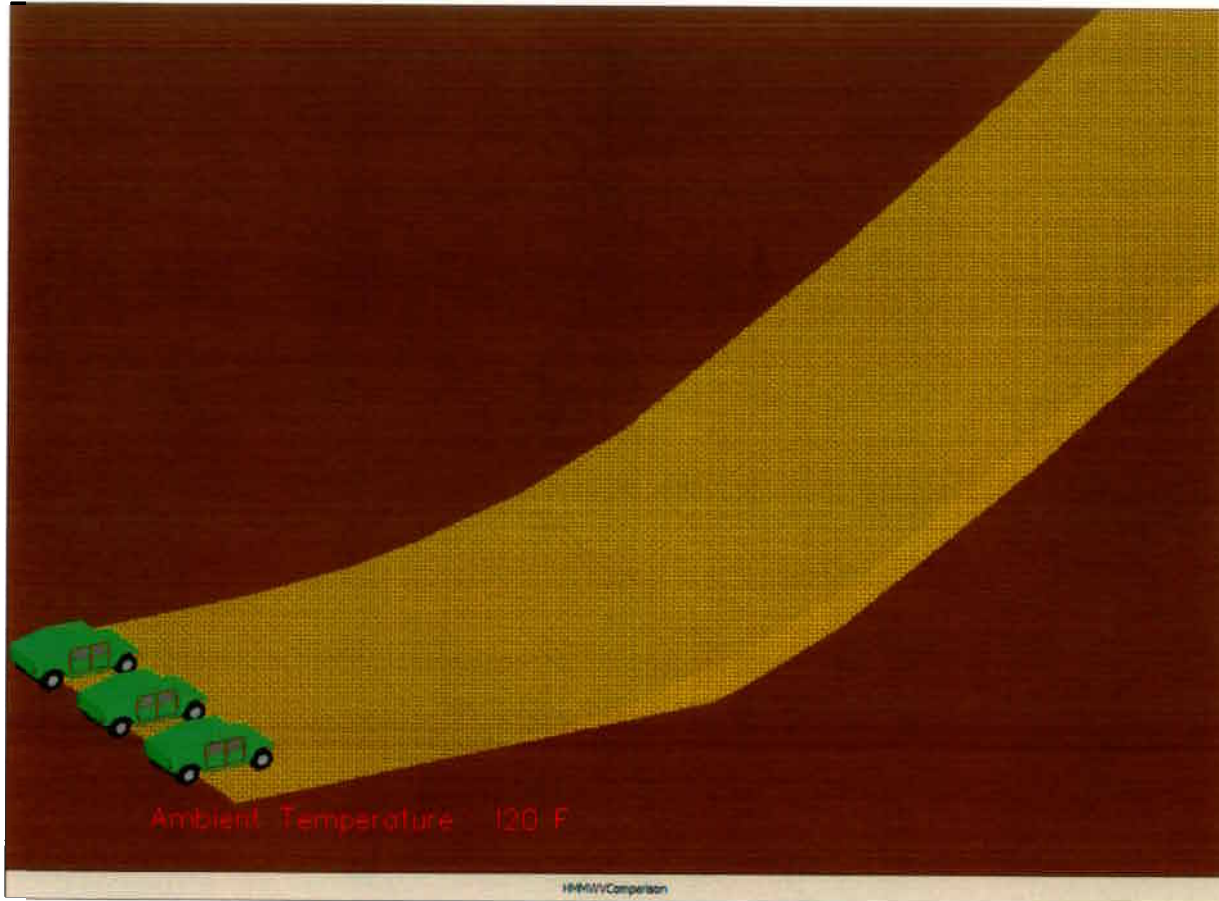
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## *Benefits:*

- Minimize number of tests
- Maximize test results
- Save time
- Reduce cost
- Enhance cooling system performance capabilities

# Thermal Testing

Unclassified



## Objectives

Maintain critical temperatures within specified limits while operating at:

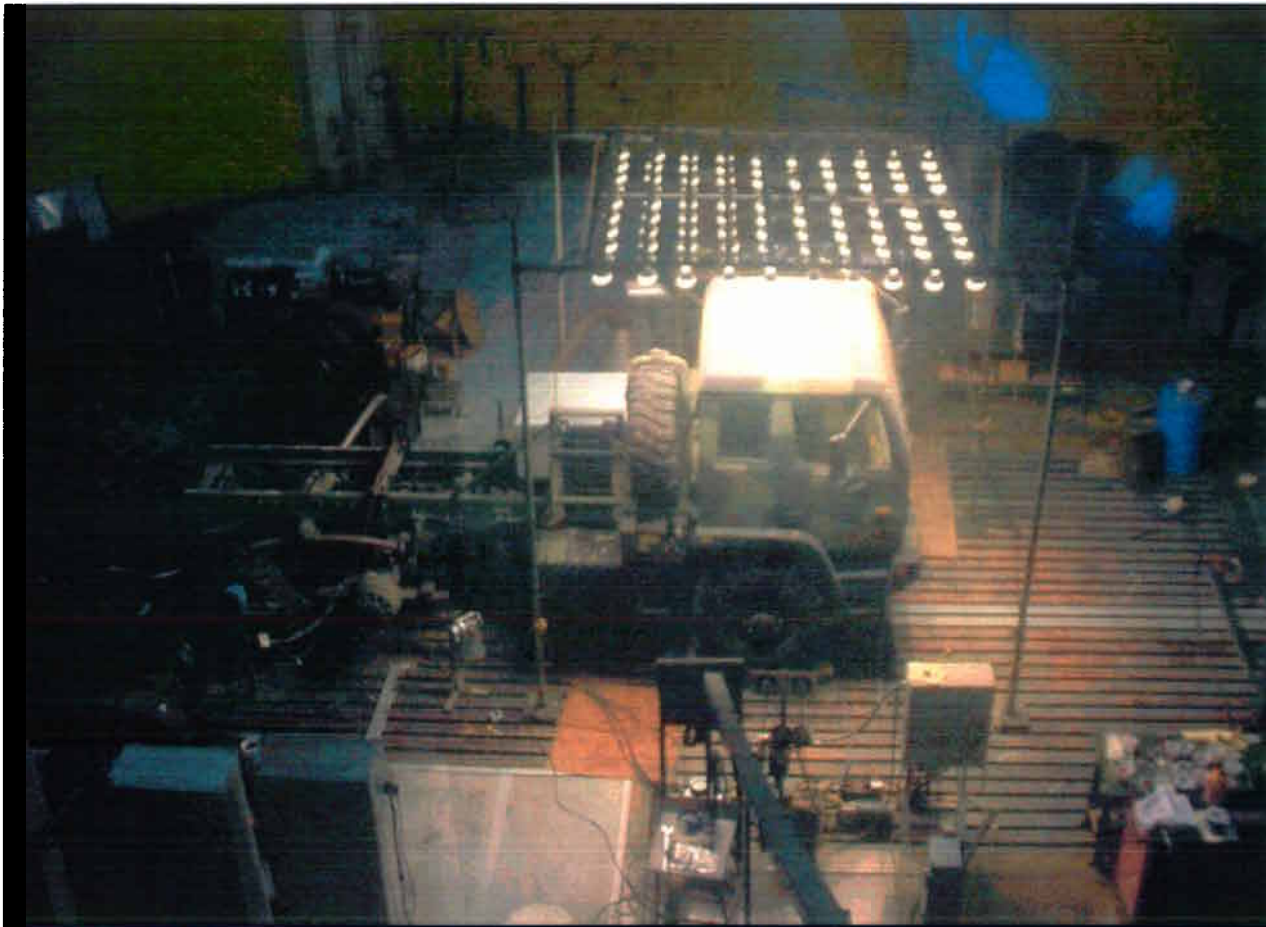
- Full power
- Full load
- Ambient 120°F

## Specified Limits

- Engine Coolant 230°F
- Engine Oil 275°F
- Transmission Oil 300°F

# Thermal Testing

Unclassified



## Test Conditions

- Full Power
- Full Load
- Ambient 120°F
- 5 mph wind velocity
- Solar radiation

## Data Captured

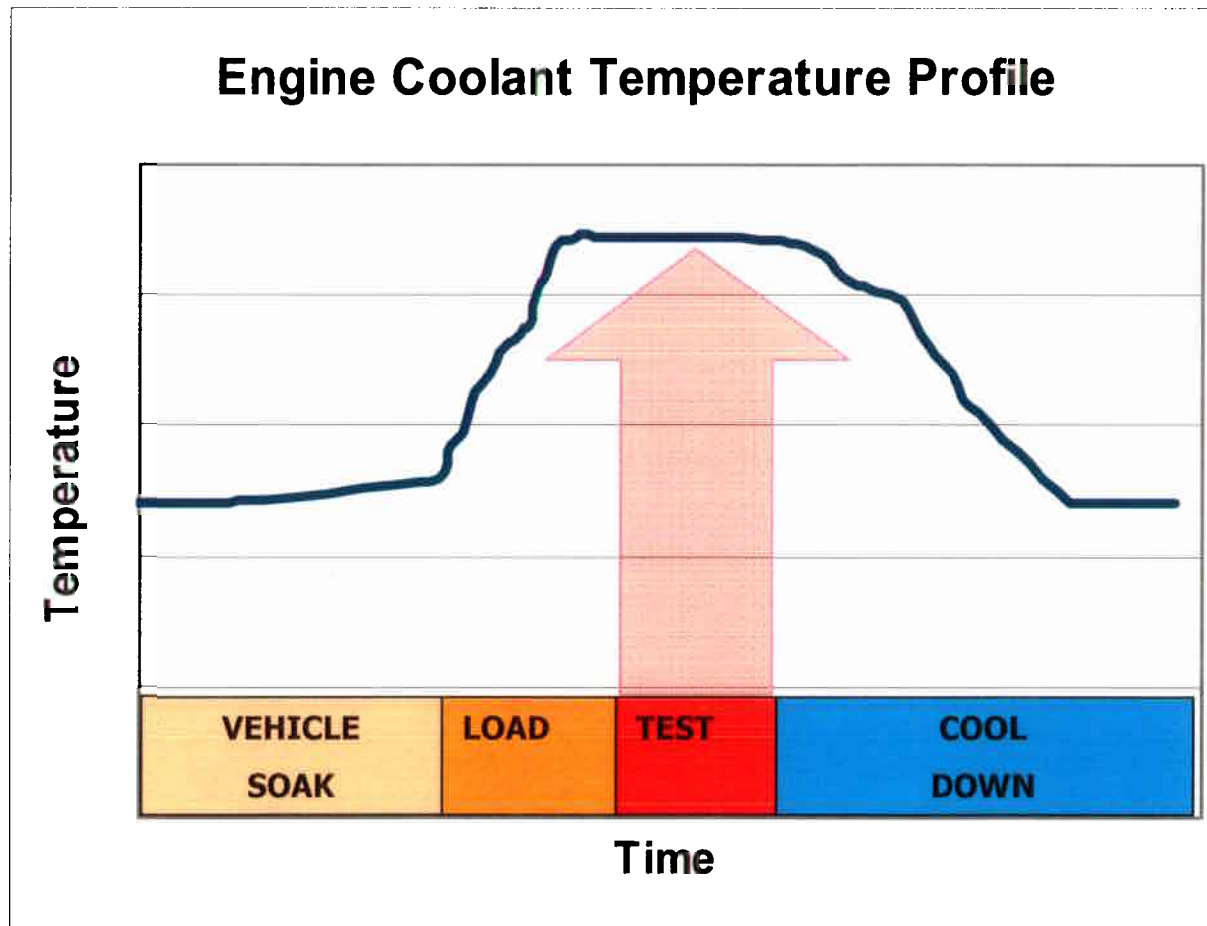
- Engine Coolant
- Engine Oil
- Transmission Oil

## Results

Determine if vehicle cooling system meets requirements in various configurations

# Thermal Testing

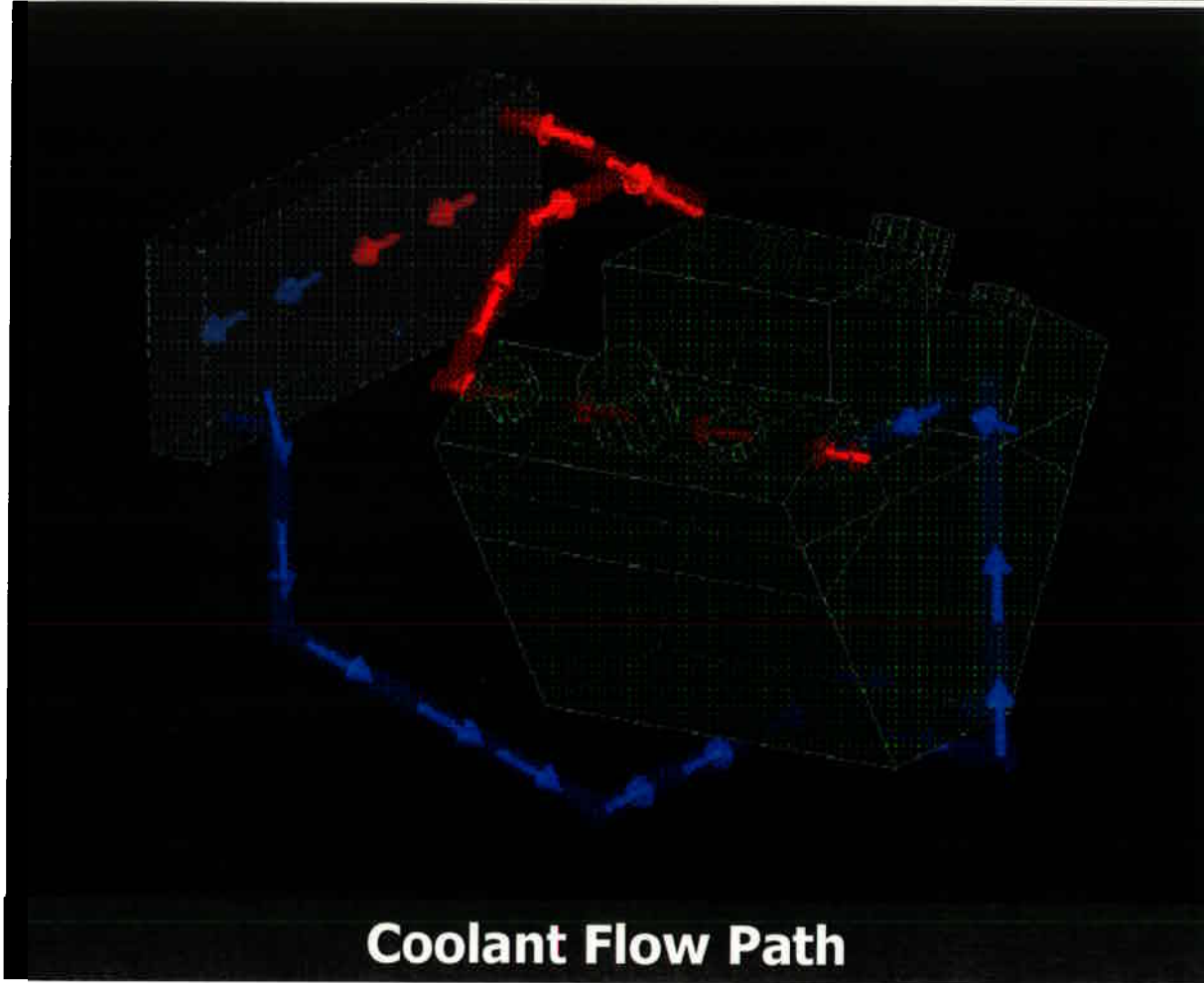
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Thermal model simulates steady state conditions during cooling testing

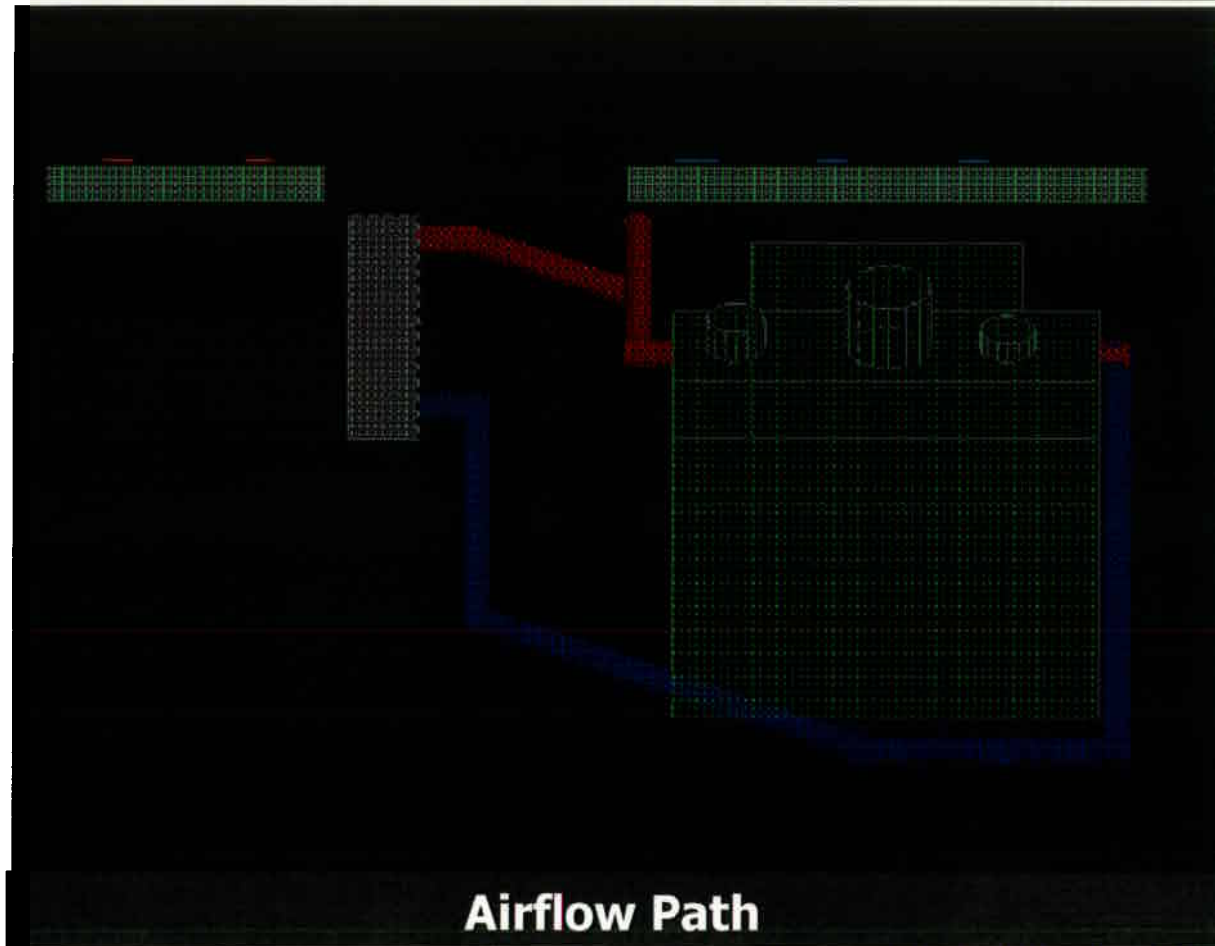


# Thermal Tool - Function



- Model the coolant and airflow heat balance
- Predict critical temperatures
- Produce same results as test

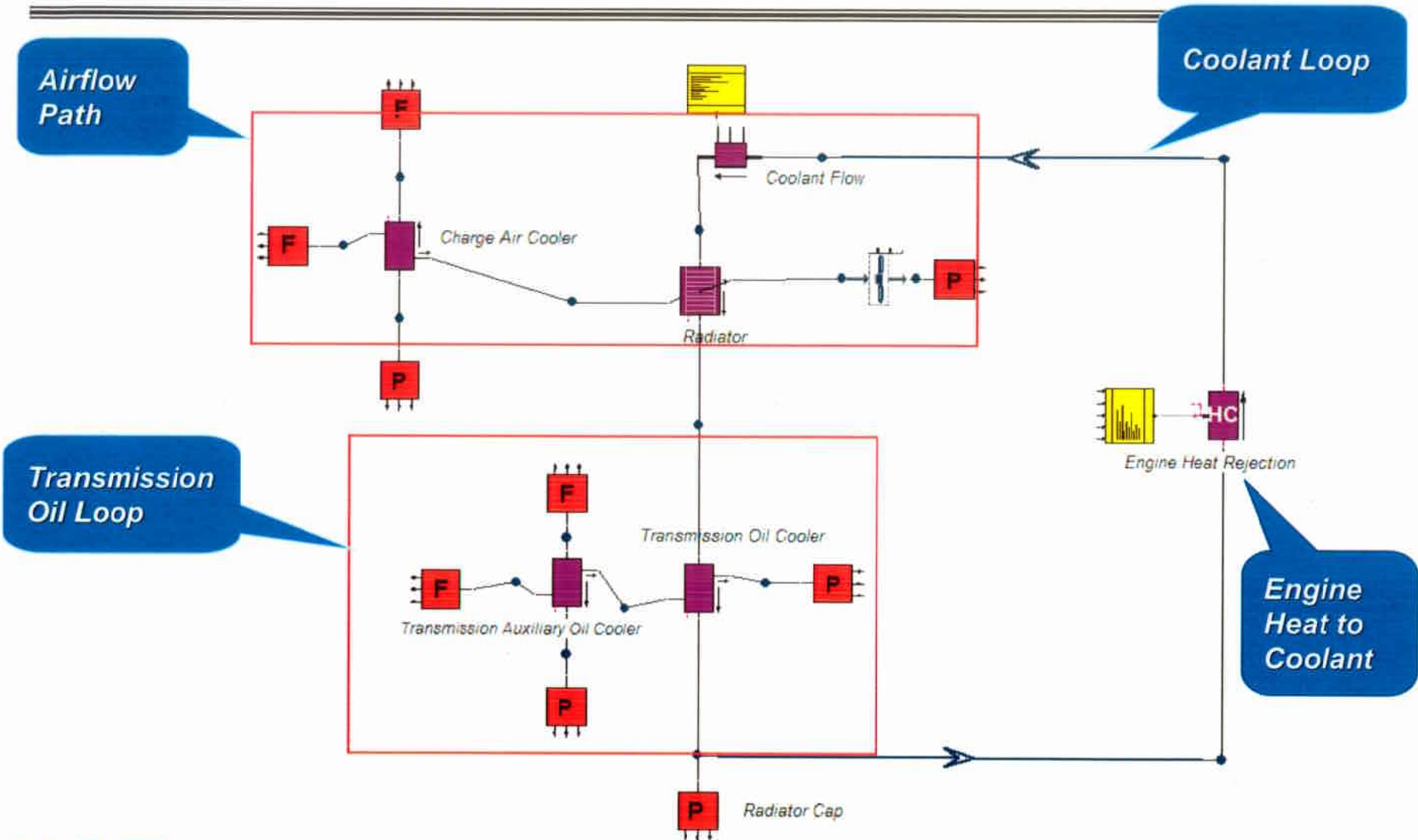
# Thermal Tool - Function



- Model the coolant and airflow heat balance
- Predict critical temperatures
- Produce same results as test

# Thermal Tool – Function

Unclassified



# Pilot Project – Medium Tactical Vehicles

Unclassified



M1087 Expandable Van



M1093 Cargo Truck



M1098 Wrecker



M1090 Dump Truck

**Commonality**

**Differences**



Common Chassis

**Chassis  
Drive Train**

**Payloads  
Mission Requirements**



Material Handling  
Equipment



Load Handling  
System



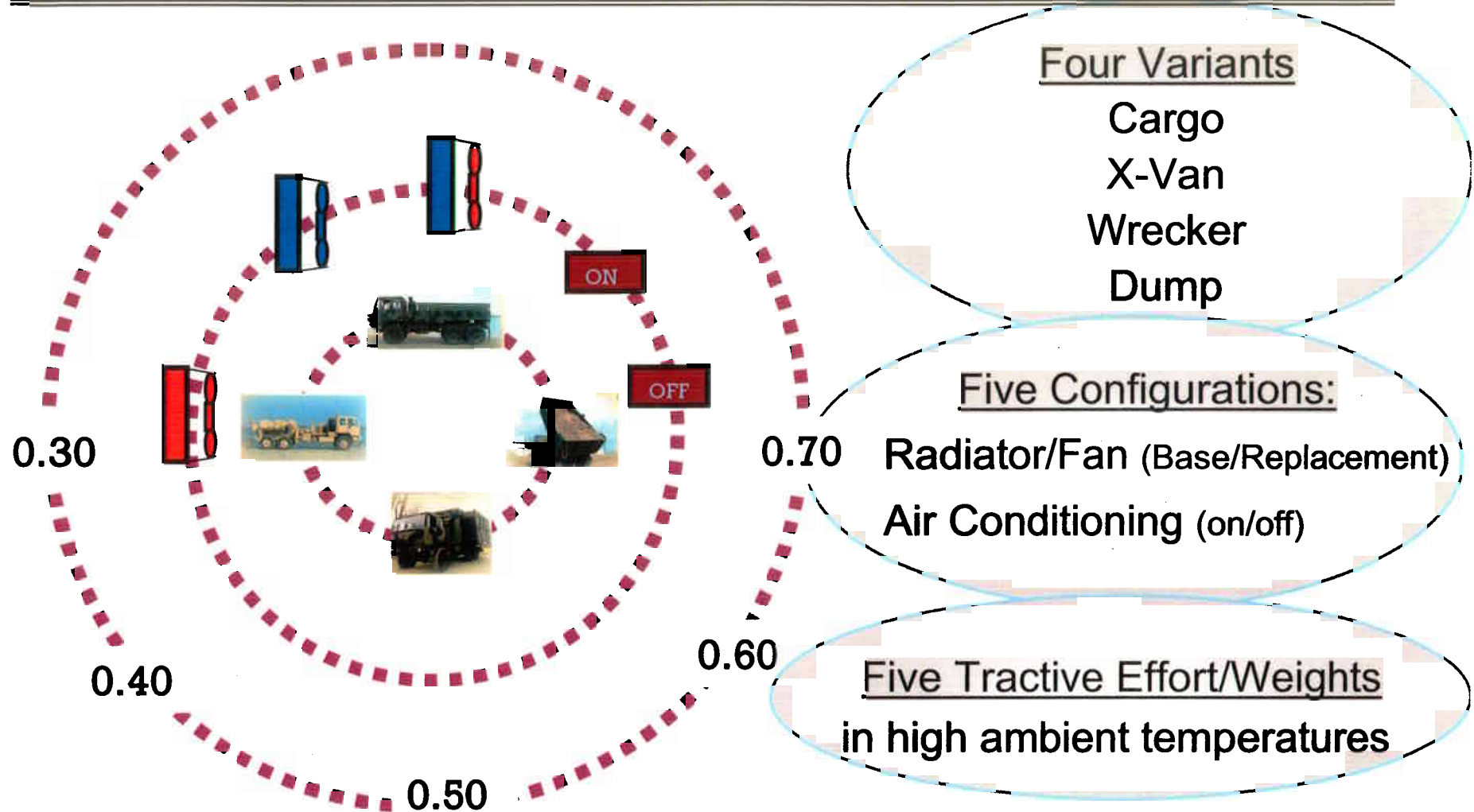
MTV



M1088A1 Tractor

# Pilot Project – Test Matrix

Unclassified



**Tradition approach only captured 40% of the desired data within this test matrix.**

Unclassified

06CV-190

# Pilot Project – Work Completed

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*Major objectives have been accomplished*

- Captured test data from four MTV variants



M1093 Cargo Truck



M1087 Expandable Van



M1098 Wrecker

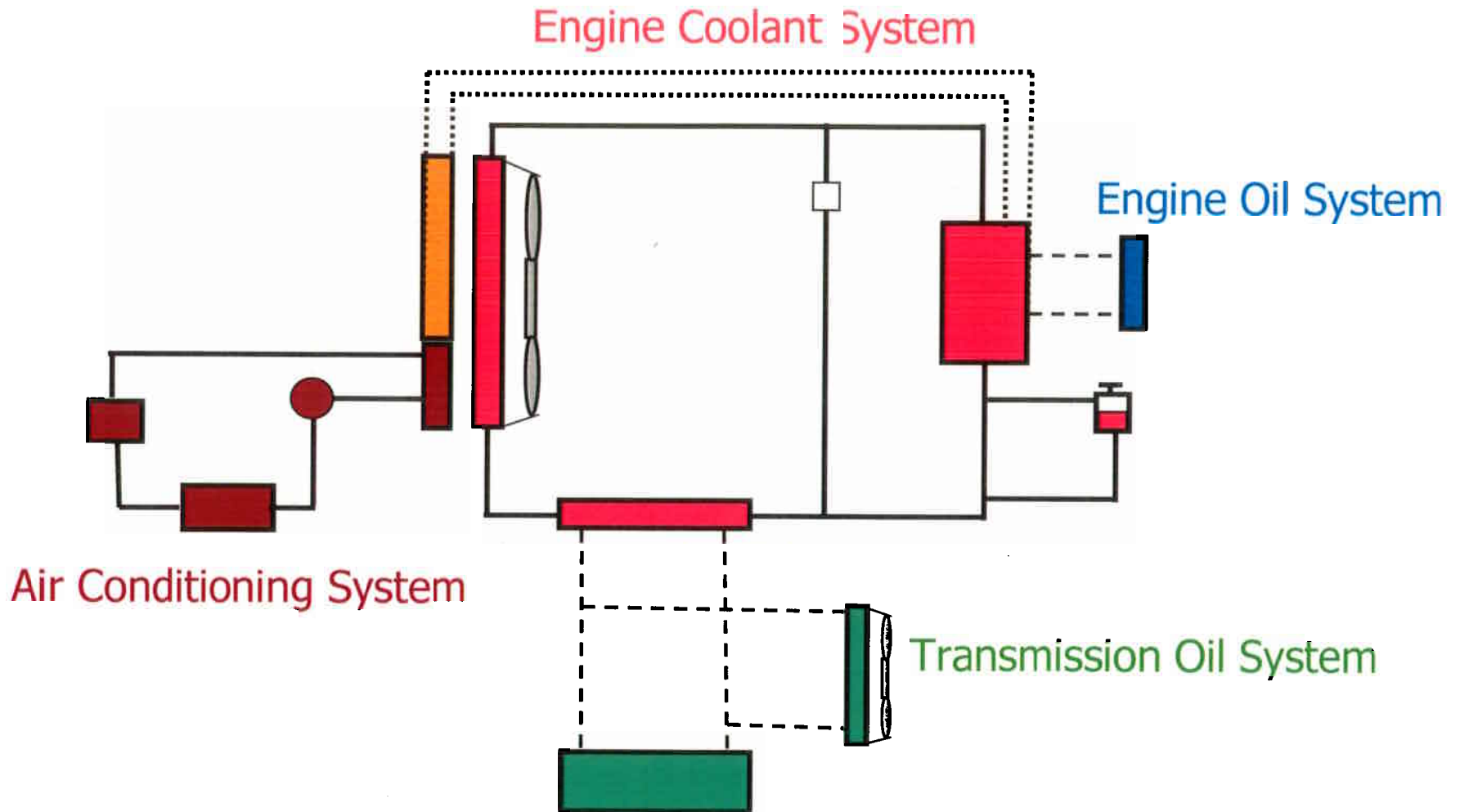


M1090 Dump Truck

- Developed several thermal models
- Validated models using actual test data

# Thermal Tool - Thermal Systems

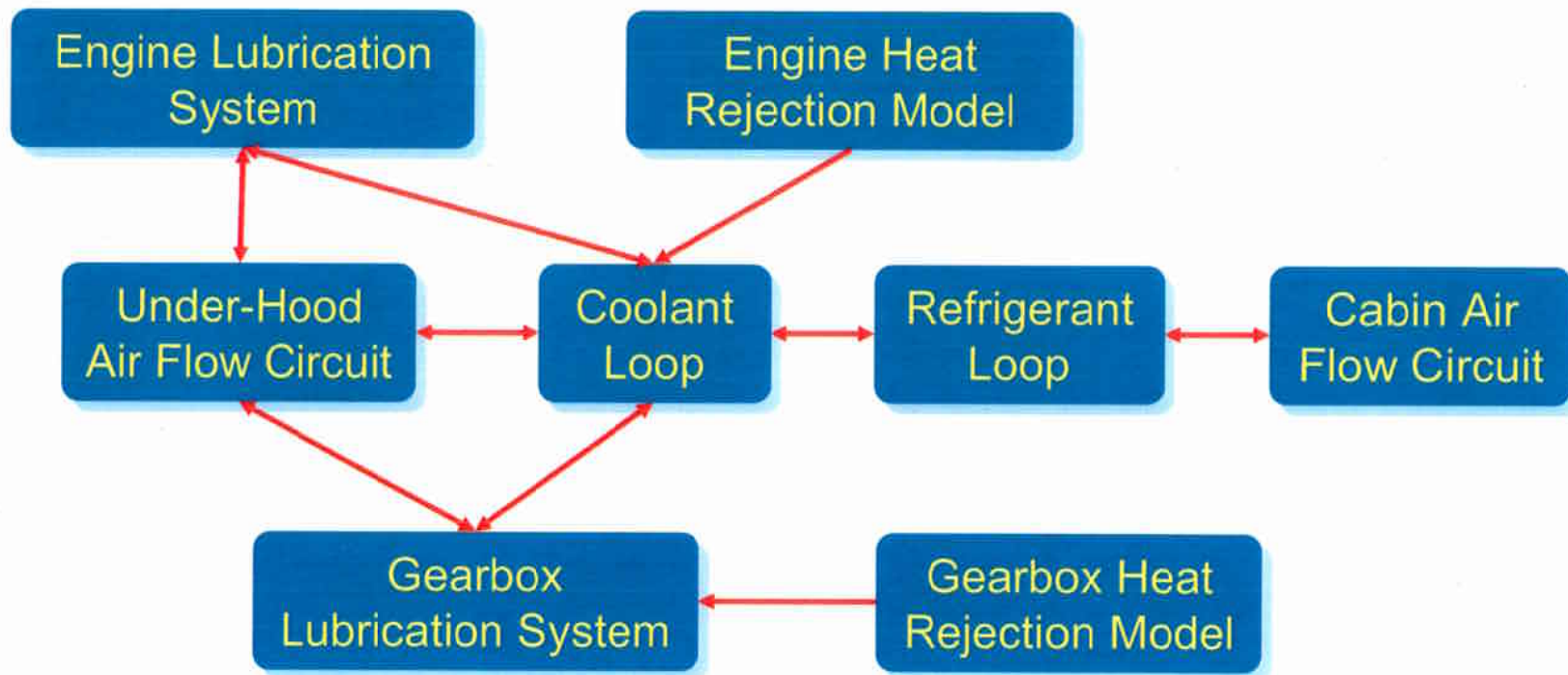
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# Thermal Tool - Responsibilities

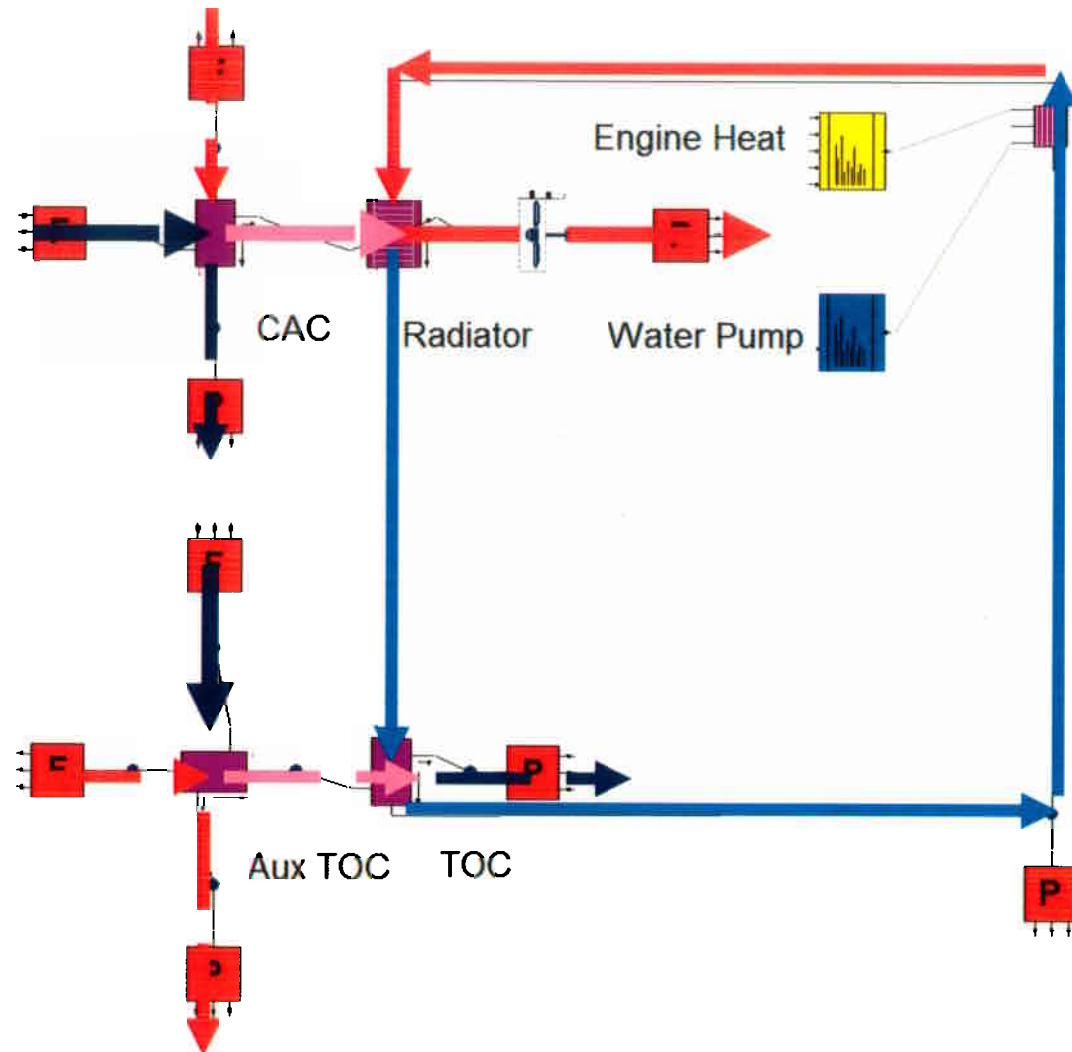
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Thermal system interaction:



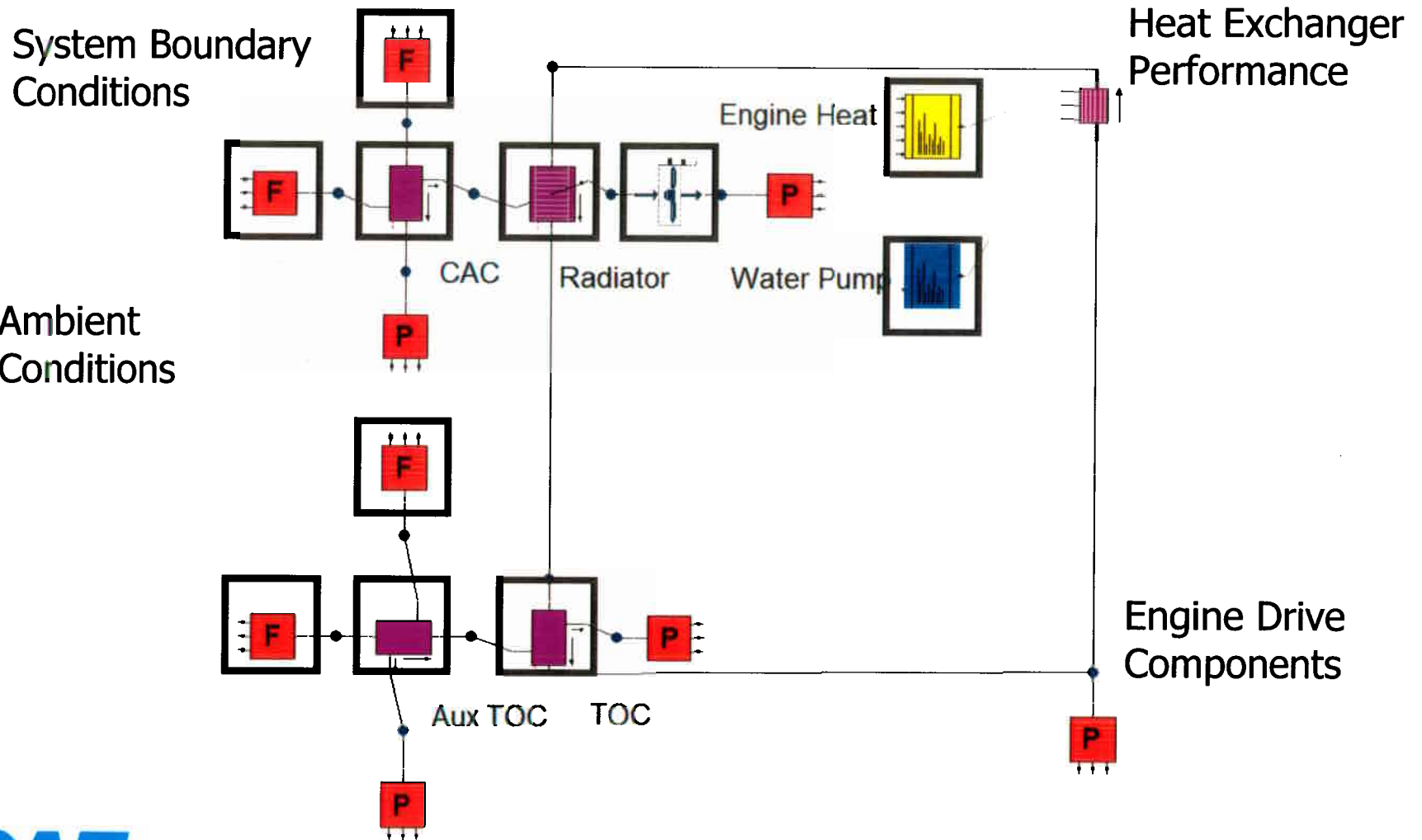
# Thermal Tool - 1D Model Set Up

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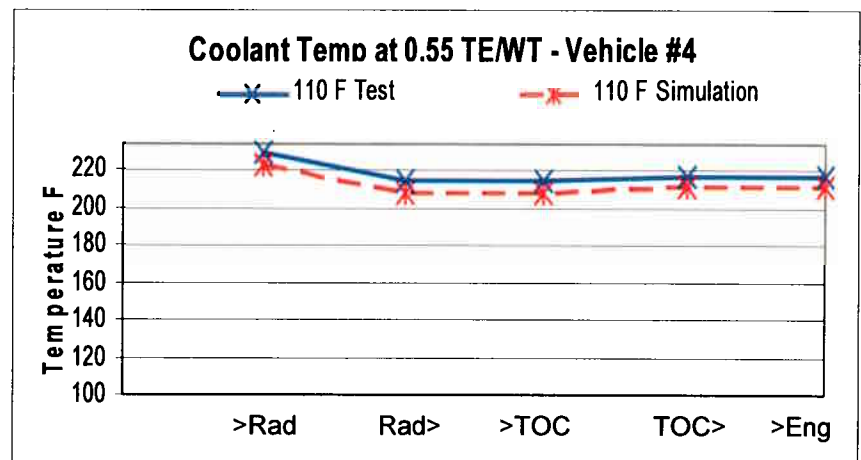
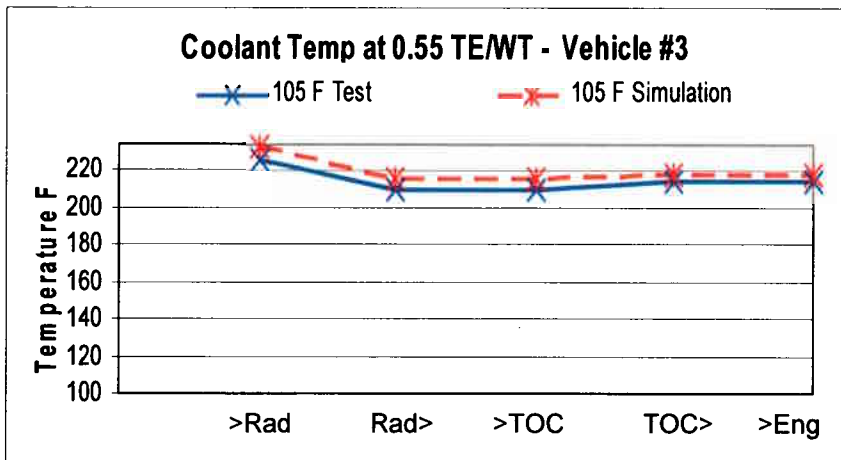
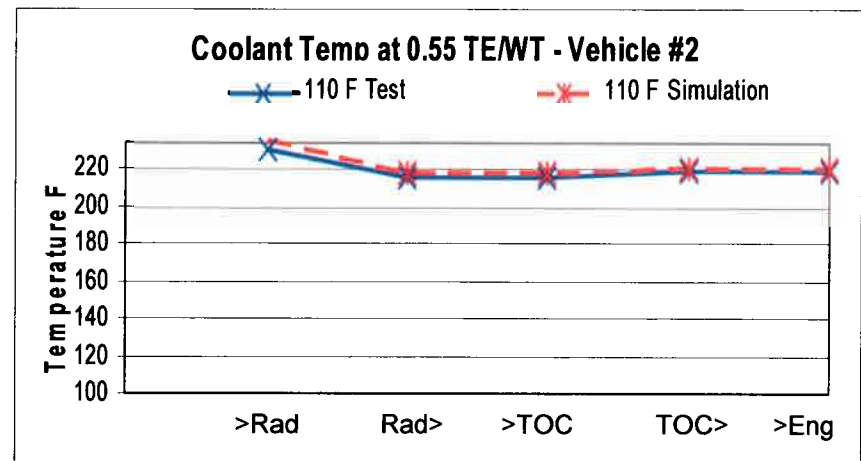
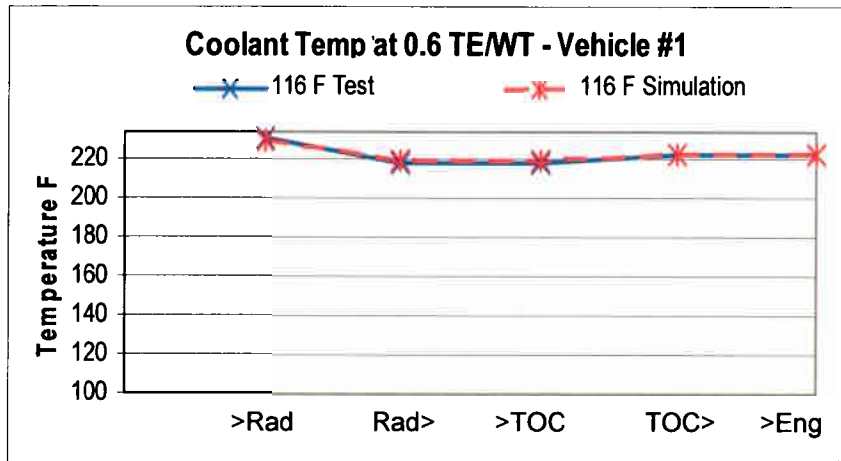
# Thermal Tool - 1D Model Set Up

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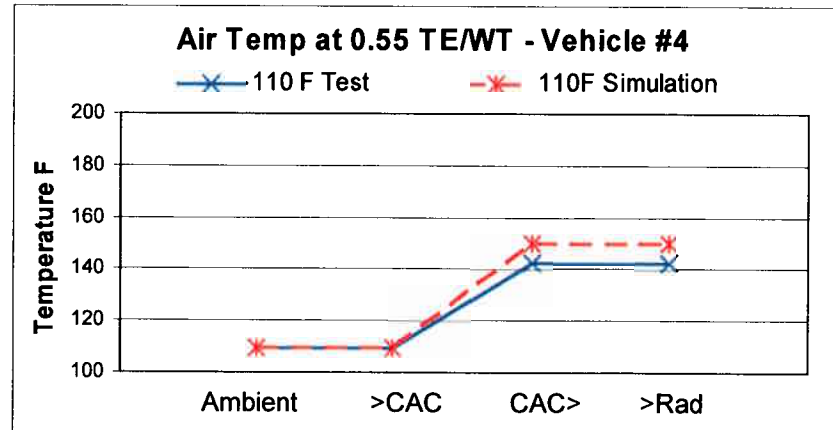
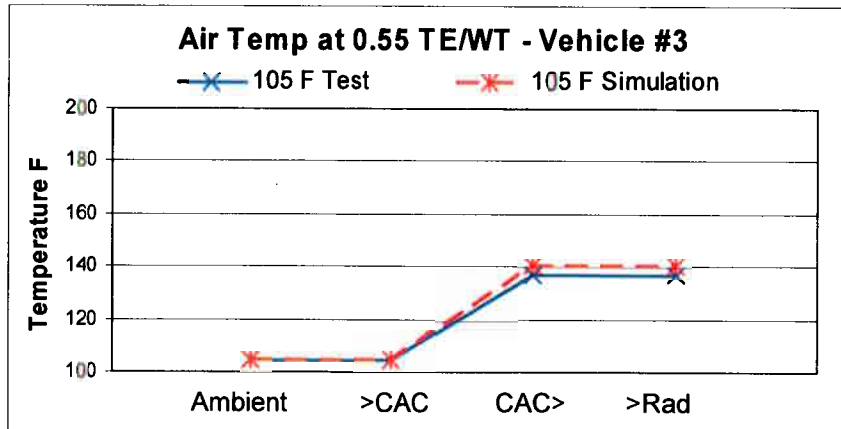
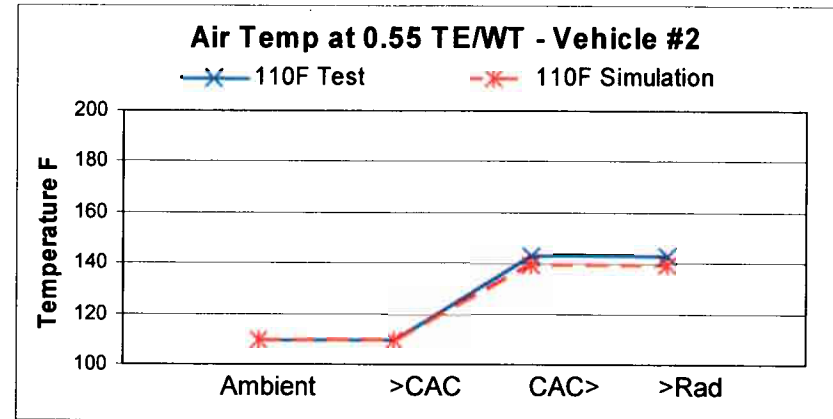
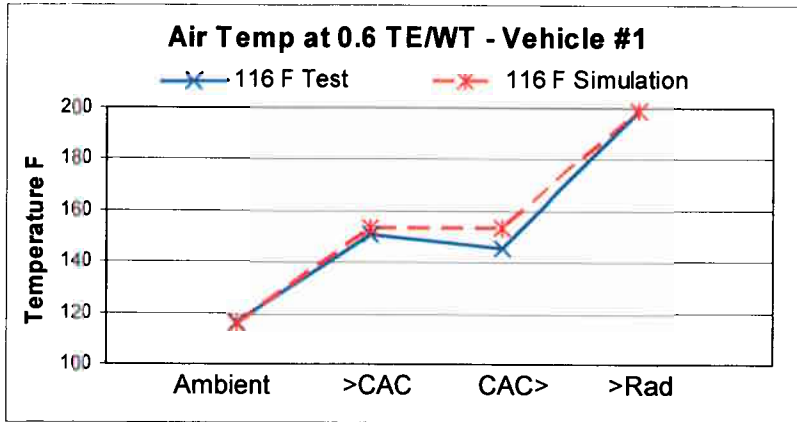
# Results – Coolant Temperature

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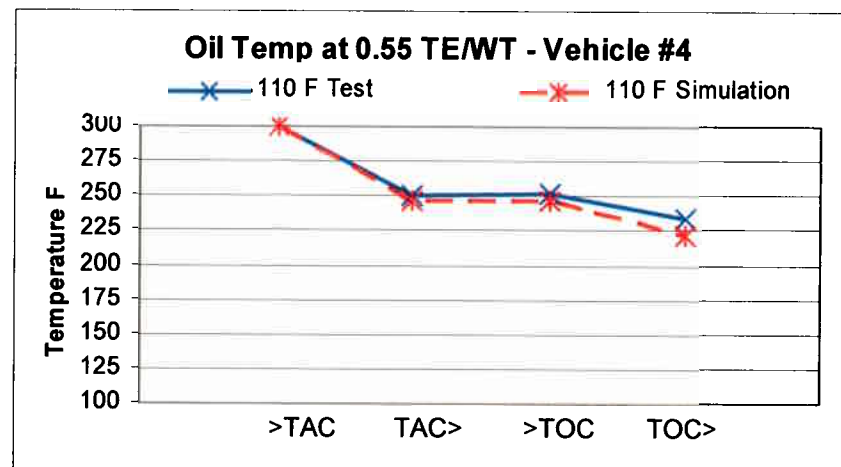
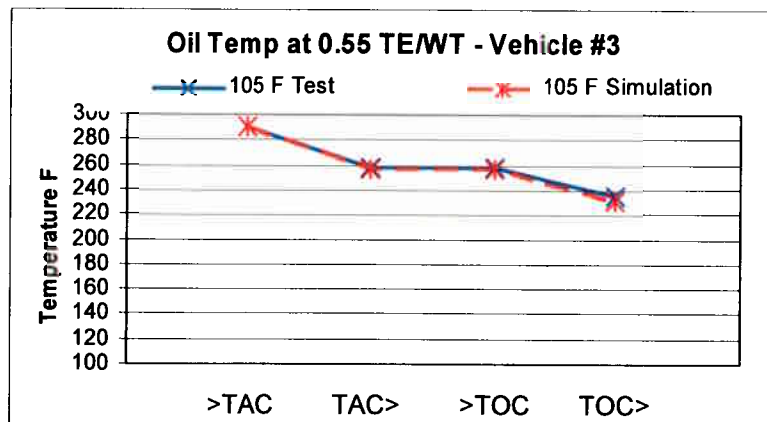
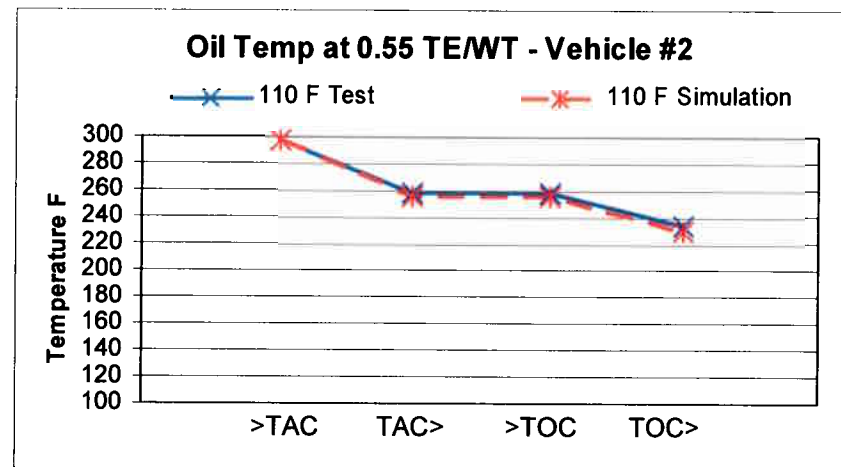
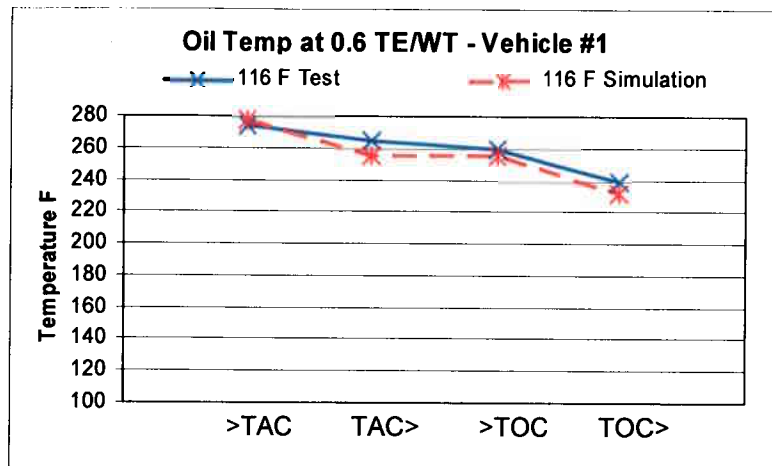
# Results – Air Temperature

Unclassified



# Results – Transmission Oil Temperature

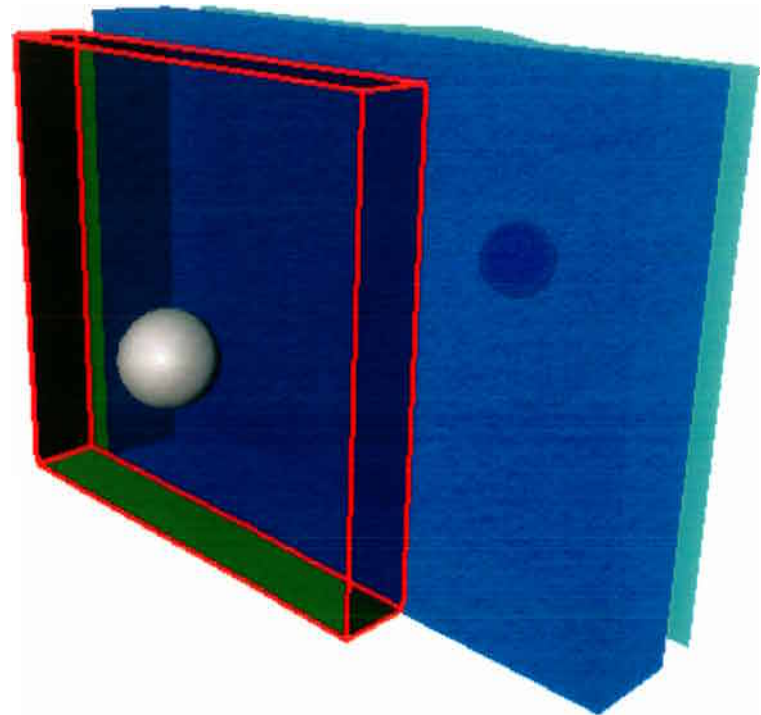
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# Next Steps – Additional Variables

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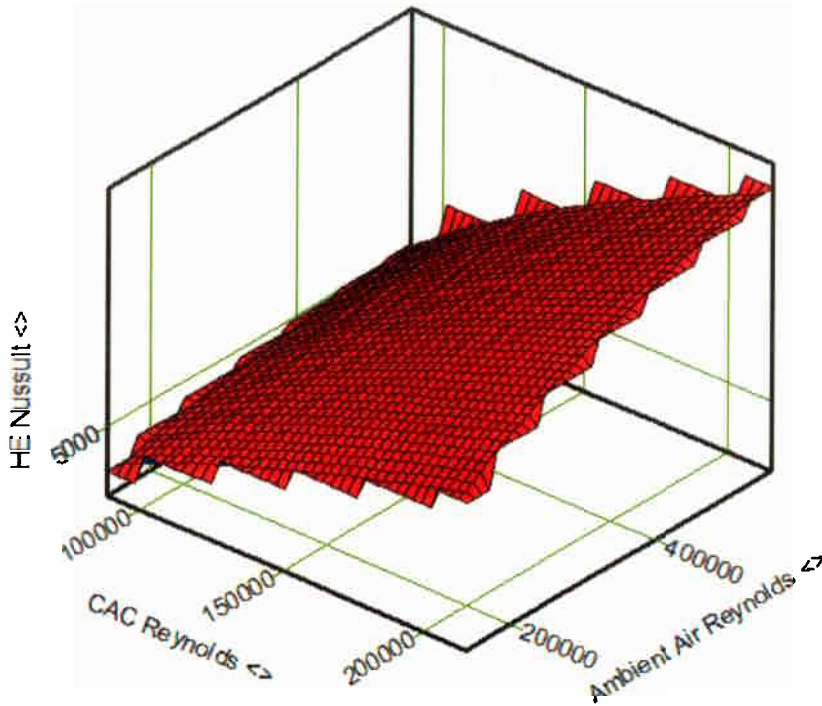
- Performance
  - Equal or better than existing exchanger under same operating conditions
- Variable Geometry
  - Height, width, and depth
- Variable Location



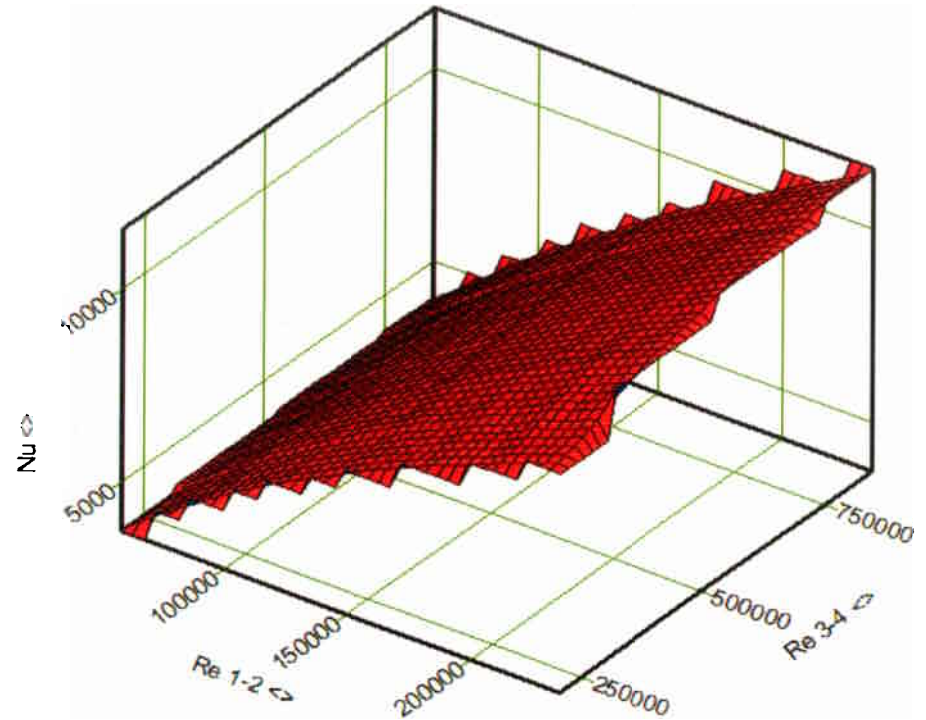
# Next Steps - Performance Input

Unclassified

Charge Air Cooler Nusselt Number vs. Re12 vs Re34 V3



CAC Nu v Re1-2 v Re3-4



# Next Steps – Automated Approach

Unclassified

Nusselt Number Calculator VS.user.xls

## Flowmaster Nusselt Number Calculator

**Project and Component Location**

Database Folder: C:\Flowmaster\_Databases\4\Databaseflow\_db Pipe Area 1: 1 m<sup>2</sup>

Project Folder: C:\Flowmaster\_Databases\4\Databaseflow\_ud Pipe Area 2: 1 m<sup>2</sup>

Project Name: AVS\_02305 Width Across Air: 1 m

Network Name: AVS\_Example Thickness in Air F: 1 m

Surface Title: Fin\_FM\_Macro\_Test Vertical Height: 1 m

**Heat Exchanger Properties**

Thickness (m): 0.001

Hot Side Fluid Type: Oil 2010 Rev 0230

Flow Area (m<sup>2</sup>): 1.0E-02

Hydraulic Diameter (m): 0.000825

Inlet Pressure (bar): 1

Air Side Fluid Type: Oil 4144 Rev 04

Flow Area (m<sup>2</sup>): 0.332

Hydraulic Diameter (m): 0.001

Inlet Pressure (bar): 1.013

**Required Calculation Steps**

- Click to populate dropdown menus with fluids from FLOWMASTER database
- Click to calculate Nusselt number
- Click to add to Flowmaster
- Update Network
- Start Flowmaster

**Results**

Temperature (°C) Heat Duty (kW)

**Note:** Highlighted cells in this column indicate values that have been limited to prevent errors.

Required Data		Optional Data (give T or Duty)				Data Retrieved from FLOWMASTER					Calculated Results								
Mass Flow Rate (kg/s)		T <sub>in</sub> [°C]		T <sub>out</sub> [°C]		Hot Side		Air Side			ΔT <sub>i</sub>		q [m <sup>3</sup> /s]		U [W/m <sup>2</sup> K]		Re <sub>hot</sub>	Re <sub>air</sub>	Nu
Hot Side	Air Side	Hot Side	Air Side	Hot Side	Air Side	Heat Duty [W]	Specific Heat [J/kg K]	s [N s/m <sup>2</sup> ]	Specific Heat [J/kg K]	Thermal Cond. [W/m K]	Viscosity [N s/m <sup>2</sup> ]	ΔT <sub>1</sub>	ΔT <sub>2</sub>	q <sub>1</sub>	q <sub>2</sub>	U	Re <sub>hot</sub>	Re <sub>air</sub>	Nu
0.32883333	0.8071904	80.8	25.4	58.57871	58.84033	2485.548	3554.88094	0.0012306	910.039763	0.027388644	1.83E-05	51.4	165	815.222	0.4129994	3551.194	454.8111	126.25494	2076.0198
1.61916667	0.8062342	80.8	27.3	75.123978	67.798300	32952.064	3595.509626	0.0013067	910.283968	0.027503045	1.84E-05	53.5	5005.62	814.533	0.1602947	3950.6894	2636.7653	125.3032	2291.6528
0.456	0.81058996	80.9	25	67.309501	65.04129	30392.572	3572.360102	0.0013074	910.226486	0.027579523	1.84E-05	51.9	2143.47	824.959	0.2498851	4227.8854	1000.0825	125.82409	2452.2617
0.87866667	0.8052338	81.5	28.8	72.557378	68.31889	31350.252	3582.872926	0.0013052	910.24888	0.027608296	1.84E-05	51.7	3505.66	817.66	0.1726747	406.0685	855.9475	125.34723	2401.7498
0.32816667	1.39111	80.7	30.4	83.052931	82.258887	32114.124	3540.120019	0.0013988	909.920959	0.02781868	1.81E-05	50.3	161.75	804.93	0.5495576	4569.7901	411.8881	219.08174	2889.896
0.3275	1.9019396	80.9	30.1	49.80532	48.67586	35975.58	3532.702244	0.0014086	909.819327	0.0280629	1.80E-05	50.8	856.36	2001.4	0.6121847	4791.177	392.8588	314.2815	2640.3903
1.95566667	0.71984489	80.4	27.3	75.639524	70.282325	32415.2	3595.803204	0.0013051	910.36778	0.027888339	1.84E-05	53.1	702.65	778.954	0.0997362	4407.721	389.5969	119.47813	2548.0738
1.2335	0.80454058	81.4	30.6	74.424703	70.3996	32348.76	3589.294369	0.0013067	910.441323	0.027738825	1.85E-05	50.8	4837.57	812.962	0.1173105	4537.863	292.3381	124.8866	2512.4127
0.65633333	1.3417882	81.9	28.3	83.888682	57.48533	40735.652	3564.90476	0.0013945	909.571201	0.027253048	1.82E-05	53	2338.77	1395.57	0.3284931	4641.801	959.78362	217.0534	2724.5265
0.9195	1.2678439	81.9	28.5	88.282985	58.959672	44019.772	3576.578866	0.0013857	910.016307	0.027741770	1.82E-05	53.9	3488.95	1381.64	0.2345096	4686.51	816.3122	214.26768	2742.4757
0.32816667	3.16297245	82.7	31.7	47.533093	44.455196	40738.619	3529.589582	0.0014122	909.778939	0.028686957	1.8E-05	51	856.42	393.81	0.6895853	5324.2238	2814.8082	802.7025	3855.6999
0.6555	1.98366702	81.7	29.5	61.26202	52.382371	47602.363	3559.95317	0.0013894	909.973318	0.027808464	1.8E-05	53.2	2333.55	2003.25	0.3850532	6054.1246	930.47233	313.4832	2986.1377
0.32883333	4	80	30	42.008433	40.86241	43970	3511.534417	0.0016291	909.674641	0.026770394	1.80E-05	50	104.71	4638.7	0.7588447	6389.5434	340.77213	639.87007	2626.4475
1.29333333	1.39406345	81.4	29.8	71.06132	63.883613	47857.436	3579.147017	0.0017005	910.171302	0.027545504	1.84E-05	51.5	4829.03	808.25	0.2667484	5671.942	2035.7257	256.9127	3294.5875
1.29433333	1.91660136	80.8	27.8	68.39028	58.25413	57721.088	3572.938034	0.0013037	909.544803	0.027208829	1.83E-05	52.9	4624.6	2016.46	0.232945	5946.2369	873.8456	314.14443	3437.7208
0.97883333	1.95521411	82.4	31.9	67.05793	58.916256	53492.877	3573.039526	0.0017075	910.072483	0.027444403	1.83E-05	50.5	3488.65	1974.91	0.3038023	6090.8063	1417.5121	305.24218	3545.8908
1.628	1.93482342	80.5	27.5	70.10810	57.173468	53680.373	3578.892082	0.0013054	909.948631	0.027288244	1.82E-05	53	5788.83	2011.24	0.1941914	5975.6704	252.119	313.22561	3477.3903
0.85783333	2.1264889	81.9	31.4	67.01706	48.888033	56745.85	3552.480491	0.0021453	909.88166	0.027059713	1.80E-05	50.5	2336.92	3244.32	0.4882889	6259.6702	891.00493	508.0285	3701.2485

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## Top Tank Temperatures

	Vehicle A	Vehicle B	Vehicle C
<b>Heat Exchangers</b>			
<b>X</b>	180 °F	200 °F	210 °F
<b>Y</b>	180 °F	200 °F	210 °F
<b>Z</b>	180 °F	200 °F	210 °F

# Next Steps - Observations

Unclassified

- 
- Simulation accurately represents cooling system performance
  - Thermal simulation simplified complex interactions
  - Initial validation process utilized:
    - Pre-processed component test data
    - Comprehensive vehicle test data
  - Process enables rapid and accurate analysis
    - Heat exchanger options
    - Multiple vehicle variants
  - Validating process for future heat exchanger evaluation

# Thanks for attending!

## Questions?

Mary Goryca, US Army Tank Automotive Research,  
Development and Engineering Center

Neil Slyva, Flowmaster USA

