Two New CRADAs

Cooling Boiling in Head Region – PACCAR Integrated Underhood Thermal and External Aerodynamics- Cummins

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Vehicle Technologies – Annual Review – June 7–11, 2010

Projects I.D. # VSS004

Coolant Boiling in the Head Region of Heavy Duty Truck Engines—CRADA PACCAR New Project (April 2010)

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Project I.D. # VSS004

Overview

Timeline

- Start - April 2010
- Finish - April 2013
- 6% Complete

Budget

- Total project funding
  - DOE share (300K to date)
  - Contractor share (100K in kind)
- Funding for FY10 (received April 2010)– $300K

Barriers

- Barriers addressed
  - *Constant advances in technology*
  - *Computation models, design and simulation methodologies*
  - *Vehicle efficiency beyond engine alone*
  - *Lower component volumes and weights*
  - *Reduce parasitic energy losses*
  - *Reduce cooling system size*
  - *Increase engine thermal efficiency*
- *Targets*
  - *R*educe essential auxiliary loads by 50 % by 2012
  - *Improve heavy truck engine thermal efficiency to 50% by2015 and to 55% by 2018*

Partners

- PACCAR (CRADA)

Objectives / Relevance

- Overall Objective
  - Understand and quantify engine coolant boiling heat transfer in heavy duty trucks for
    - Increased cooling system efficiency with reduced size cooling systems
    - Increased engine thermal efficiency through optimized thermal control
- Specific programmatic objectives
  - Experimentally determine boiling heat transfer rates and limits in the head region of heavy duty truck engines
  - Develop predictive mathematical models for boiling heat transfer results
  - Provide measurements and models for development/validation of heavy duty truck engine computer codes
- Relevance to VT Program
  - Reduce parasitic energy losses
    - Reduce size, weight and pumping power of coolant system
  - Increase engine thermal efficiency
    - Optimize engine cooling
    - Improve engine temperature gradients
  - Overcome barriers
    - Technology advances in coolant boiling
    - Computational model improvement for heavy vehicle engine analysis

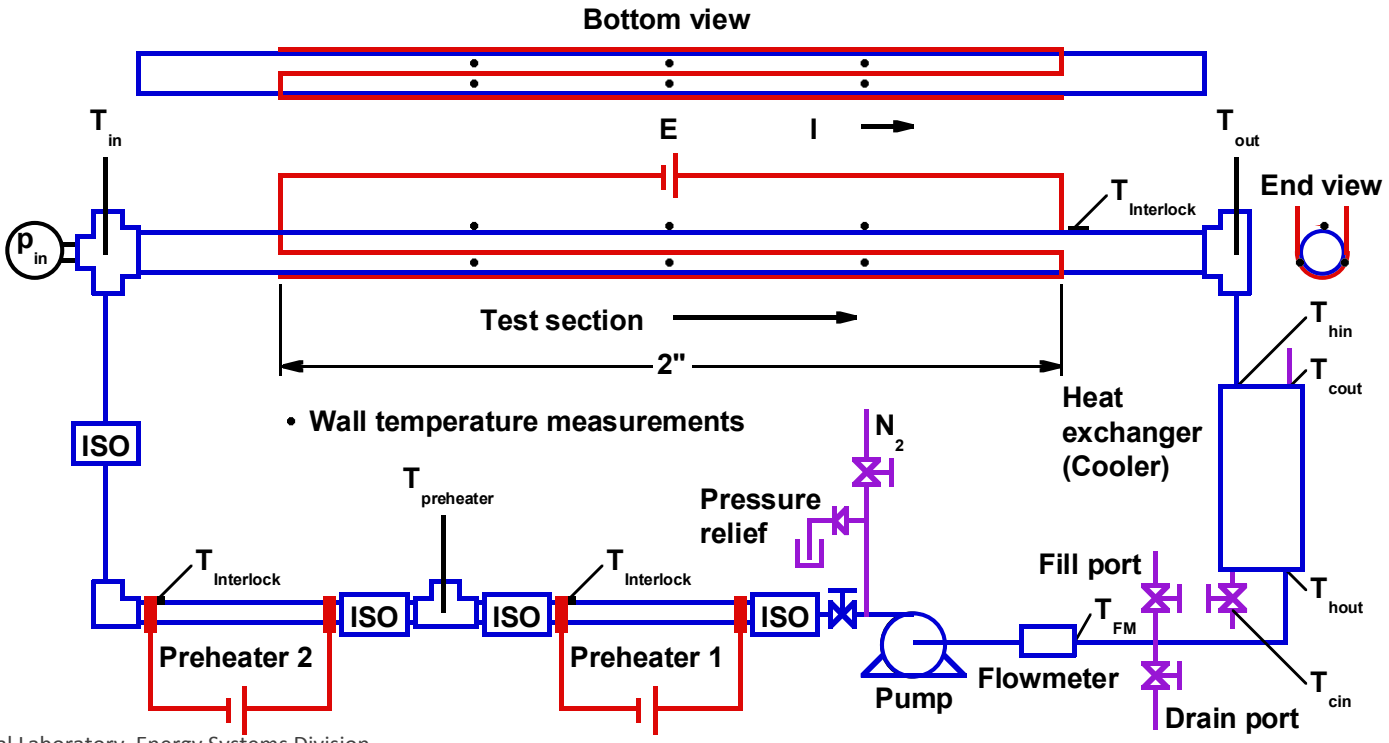
Milestones

- Status
  - Experimental system design , completed April 2010
  - Procurement of materials, components, instruments, & sensors, started April 2010

- FY 2010 Milestones
  - Complete procurement of experimental facility components, June 2010
  - Complete experimental facility fabrication, September 2010
  - Complete data acquisition system hardware and software, September 2010
  - Initiate facility preliminary operation and checkout, September 2010

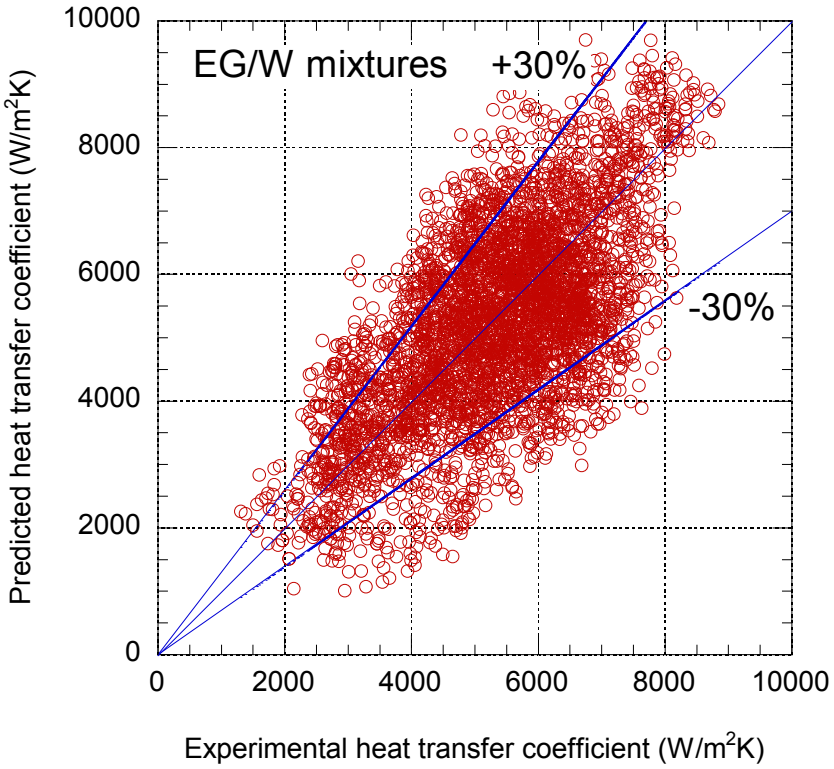
Experimental Approach

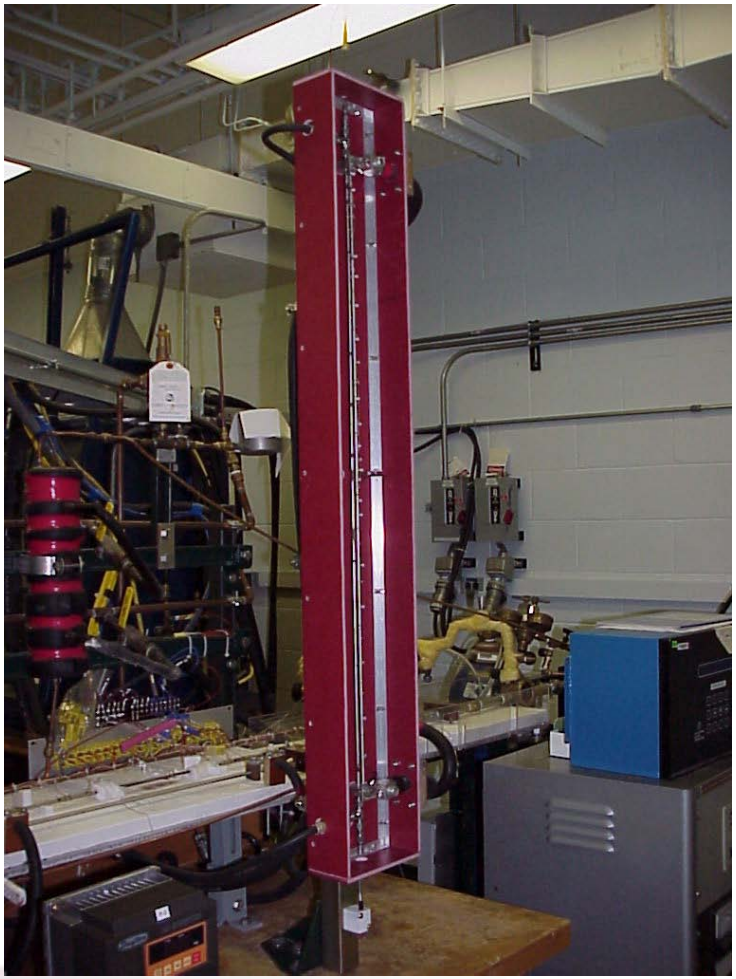
- New experimental facility based on ANL experience with boiling of 50/50 mixtures
  - Simulation of cylinder head in 500 hp diesel engine
  - Geometry, flow and energy simulation
  - Boiling of 50/50 mixture of ethylene glycol and water
- Unique experimental technique developed at ANL from previous 50/50 boiling tests
- New application to very high heat flux boiling conditions in cylinder head



Technical Accomplishments – Prior Program

- Completed program on boiling of ethylene glycol/water mixtures under different conditions and geometry than the present case
- Obtained, interpreted and correlated experimental data
- 50/50, 60/40, 40/60 mixtures
- Mass flux = 40-170 kg/m^{2}s





Technical Accomplishments – Program Start

- Completed CRADA agreement with PACCAR
  - Agreed upon geometry, flowrates, materials & complimentary effort
- Completed design of new experimental test facility and support systems
  - Designed unique new test facility for ethylene glycol/water boiling
  - Designed test section to simulate the head region of heavy duty truck engines
  - Designed instrumentation and heating for test section
  - Initiated adaptation of unique data acquisition/reduction software for facility
- Completed procurement of materials and components for facility
- Initiated fabrication of experimental test facility

Collaboration with Other Institutions

- Partner
  - PACCAR, Inc.
  - CRADA in place for joint program
- Experimental work to be performed by ANL at ANL
- Computer code optimization/validation – PACCAR
- Interpretation and evaluation of results – combined effort

Proposed Future Work

- FY 2010
  - Complete fabrication of new experimental facility
    - Closed loop system
    - Instrumentation
    - Data acquisition
  - Initiate check out of facility
    - Perform heat loss experiments
    - Perform control experiments with single-phase flow
    - Perform preliminary flow boiling tests
    - Interact with PACCAR on initial data
- FY 2011
  - Complete facility check out
  - Initiate flow boiling experiments
    - Interact with PACCAR on data
  - Provide PACCAR data for computer development/validation
    - Interact with PACCAR on results, modifications, conclusions

Summary

- Combined innovative program under CRADA with PACCAR
  - Heavy duty truck diesel engine simulation
- Utilize/optimize coolant boiling to
  - Reduce coolant system size and power consumption
    - Reduce parasitic energy use
  - Improve control of engine temperatures
    - Provide potential for increased engine thermal efficiency
- Rely on results and techniques from previous ANL tests
  - Boiling of engine coolants under different conditions than in this program
  - Accurate data reduction technique for boiling of binary mixtures
  - Knowledge gained of results and trends associated with 50/50 mixture boiling
- Combined experimental and computer code effort with PACCAR

Integrated Underhood Thermal and External Aerodynamics for Heavy Vehicles – CRADA with Cummins NEW Project (Start July 2010)

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Project ID
VSS004

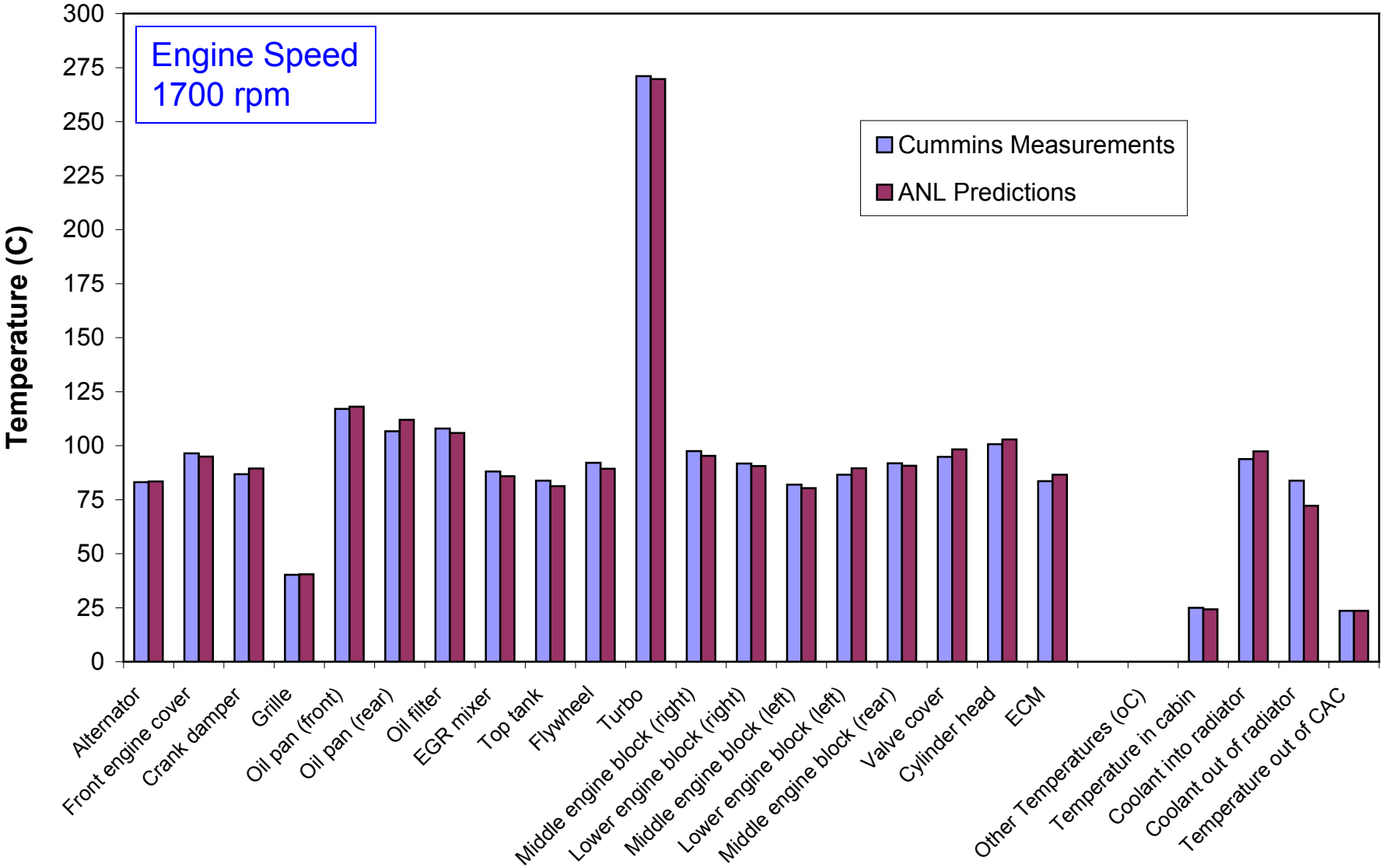
ANL-Cummins CRADA

- Background:
  - Engine makers work closely with OEM's for installation issues as well as cooling system optimizations
  - ANL's novel predictive analytical capability helps redesign of an underhood configuration to meet emissions reduction targets while keeping the energy efficiency considerations in perspective
  - Initial development through a CRADA with Caterpillar for off-road vehicles (2002-2005)
  - Modeling extensions (cooling system and EGR) through a CRADA with Cummins for class-8 heavy-duty vehicles (2006-2009)
- Scope of new ANL-Cummins CRADA with proposed participation of FedEx
  - Integrated external aerodynamic and underhood thermal analysis for heavy vehicles
  - CRADA package is expected to be submitted for approval by July 2010

Accomplishments and Progress

- Most recent effort focused on the thermo-fluid system modeling of Cummins ISX engine in a “generic” truck configuration
- Tests at Cummins Vehicle Integration Laboratory completed in 2007
  - Tests covered 1200-1700 rpm engine speeds with varying wind, fan, and pump speeds, and coolant flow rates
  - ANL staff participated in both planning and execution of the tests
- ANL completed the analysis of tested configurations and performed the comparisons with experimental data in 2009
  - CAD model of the “generic truck” used is prepared by ANL staff to avoid concerns for proprietary data
  - Results indicate that the temperatures and distributed heat rejection rates can be estimated within reasonable accuracy
- Cummins has adopted the heavy vehicle underhood thermal assessment practices developed as part of this CRADA
  - Training of their R&D center staff at Cummins Research and Technology India (CRTI) took place in May 2008 in Pune, India

Accomplishments and Progress

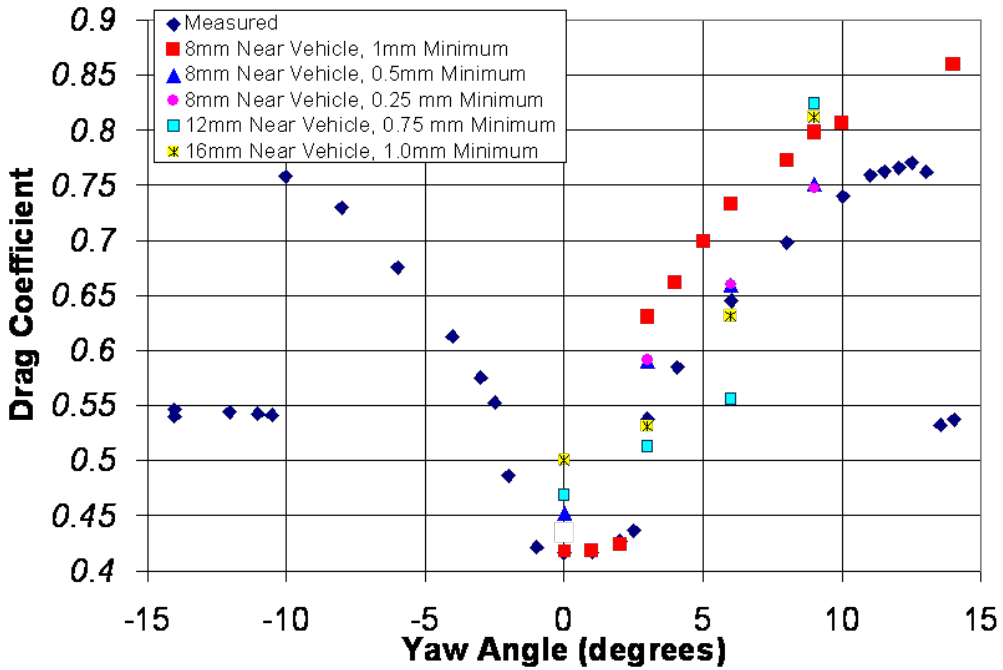


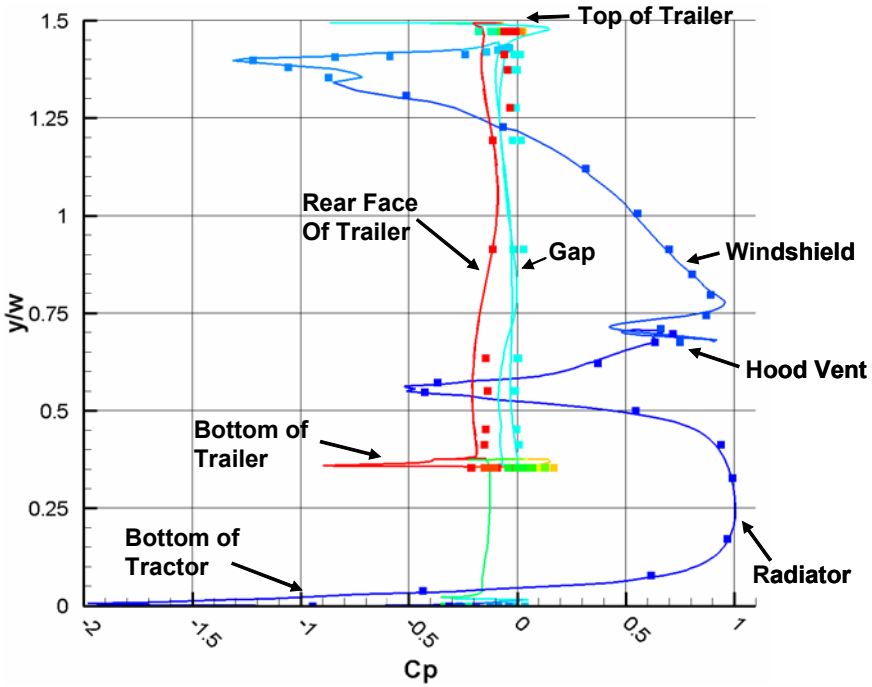
Objectives of new ANL-Cummins CRADA

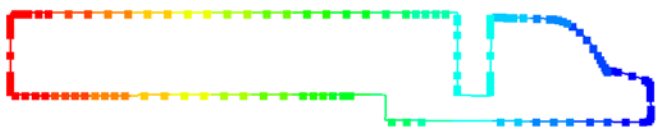
- Optimal design of vehicle thermal system is important to achieve fuel efficiencies through radiator size reduction
  - A comprehensive analytical capability is needed to make drag reduction assessments for different underhood design options
- An integrated underhood thermal and external aerodynamics analysis capability is proposed
  - For redesign of underhood configuration while keeping aerodynamic considerations in perspective to meet energy efficiency targets
- Modeling approach will be based on combined use of commercial 1-D network flow and 3-D CFD models
  - ***Flowmaster*** for cooling system and engine modeling to account for thermal energy balance and heat distribution inside the engine through 1-D network of flow loops
  - ***Fluent*** for underhood and external air flow to address multi-dimensional flow, heat transfer and aero-drag assessments

ANL Experience with Heavy Vehicle Aerodynamics

- ANL predicted drag coefficient for the Generic Conventional Truck-Trailer Model (GCM) at zero yaw within 1% of value measured by NASA
  - Using an approximately 8 million cell model requiring ~200 CPU hours (can be completed in ~8 hours using 4 dual quad core nodes)
- Predictions are within 1-3% at low yaw angles and 5-7% at nominal yaw angles for models of similar size







Collaboration Opportunities with FedEx

- Take advantage of extensive Argonne experience with applying commercial tools for prediction of aerodynamic characteristics of tractor-trailer geometries
  - Analyze prototypical FedEx configuration with two-trailers and shorter tractor with day-cab
  - Compare the results for FedEx configuration with a standard truck design using single trailer and longer tractor with sleeper-cab
- Based on the findings from comparisons, propose practical ideas to reduce aerodynamic drag
  - Ideas could include closing tractor-trailer and/and trailer-trailer gap, side-extender, bottail and underbody devices, curtains, and different roof-fairing designs for shorter day cab
- Complete the analysis of ideas to evaluate their fuel-savings potential and compare the results with the fuel consumption data collected by FedEx from controlled road tests

Summary

- Novel modeling technique developed at ANL for underhood thermal analysis will be extended to include assessments for external aerodynamics
  - It will enable improvements in fuel economy through significant reductions in parasitic losses resulting from thermal design and aerodynamic drag
- Argonne's role is to identify near-term opportunities for incorporation of high-fidelity numerical simulations into design cycle by demonstrating the potential of integrated underhood-thermal and external-aerodynamics simulations
  - Provide independent assessment, and guidance for use, of current generation commercial tools for underhood thermal analysis and aerodynamic simulations
  - Evaluate effects of tractor and trailer design changes, and application of add-on devices, on aerodynamic performance