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

This presentation does not contain any proprietary, confidential, or otherwise restricted information.
Overview

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

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

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

Targets
- Reduce essential auxiliary loads by 50 % by 2012
- Improve heavy truck engine thermal efficiency to 50% by 2015 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

Argonne National Laboratory, Energy Systems Division
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/m²s

![Graph showing predicted versus experimental heat transfer coefficients for EG/W mixtures.](image)
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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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

Engine Speed 1700 rpm

Temperature (°C)

- Alternator
- Front engine cover
- Grille
- Oil pan (front)
- Oil pan (rear)
- Oil filter
- Top tank
- Flywheel
- Turbo
- Middle engine block (right)
- Lower engine block (right)
- Middle engine block (left)
- Lower engine block (left)
- Middle engine block (rear)
- Valve cover
- Cylinder head
- ECM
- Other Temperatures (°C)
- Temperature in cabin
- Coolant into radiator
- Coolant out of radiator
- Temperature out of CAC
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 multidimensional 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/or 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