# Application of Robust Design and Advanced Computer Aided Engineering Technologies

## Cooperative Research and Development Final Report

## CRADA Number: CRD-04-143

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In accordance with Requirements set forth in Article XI.A(3) of the CRADA document, this document is the final CRADA report, including a list of Subject Inventions, to be forwarded to the Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

**CRADA Number:** CRD-04-143

**CRADA Title**: Application of Robust Design and Advanced Computer Aided Engineering Technologies

**Parties to the Agreement**: Oshkosh Corporation

**Joint Work Statement Funding Table showing DOE commitment**:

| Estimated Costs | NREL Shared Resources |
|---|---|
| Year 1 | $ 00.00 |
| Year 2 | $ 00.00 |
| Year 3 | $ 00.00 |
| TOTALS | $ 00.00 |

**Abstract of CRADA work**:

Oshkosh Corporation (OSK) is taking an aggressive approach to implementing advanced technologies, including hybrid electric vehicle (HEV) technology, throughout their commercial and military product lines. These technologies have important implications for OSK's commercial and military customers, including fleet fuel efficiency, quiet operational modes, additional on-board electric capabilities, and lower thermal signature operation. However, technical challenges exist with selecting the optimal HEV components and design to work within the performance and packaging constraints of specific vehicle applications.

OSK desires to use unique expertise developed at the Department of Energy's (DOE) National Renewable Energy Laboratory (NREL), including HEV modeling and simulation. These tools will be used to overcome technical hurdles to implementing advanced heavy vehicle technology that meet performance requirements while improving fuel efficiency.

**Summary of Research Results**:

NREL's work areas to support OSK's HEV R&D portfolio were focused in four main tasks. These included tactical vehicle cabin thermal modeling, fuel efficiency and performance modeling of medium duty military vehicles, design space visualizer development, and MTVR chassis dynamometer fuel economy testing.

NREL built a CFD mesh based on CAD data provided by OTC in support of the JLTV cabin thermal modeling task. CFD simulations were performed to determine the thermal performance of a JLTV. NREL provided feedback on a thermal soak/cooldown test procedure and used data from the test program to validate the thermal model. A CoolCalc model of the JLTV was built to calculate the A/C capacity required. Results compared favorably with the CFD results. Differences between the Coolcalc and RedDot assumptions were responsible for differences between the CoolCalc model and RedDot A/C capacity estimates. Understanding these differences helped to improve modeling assumptions. CoolCalc was also used to model an up-armored design case and estimate impacts on thermal loads.

Under this task NREL, also developed a spreadsheet to size heat exchangers, including air side flow and pressure drop. OTC used the results from the spreadsheet as input for detailed Fluent simulations. NREL built a CoolCalc model of the TAPV from information provided by Oshkosh. The model was used to study both steady-state and transient HVAC loads. For steady-state, the impacts of insulation and air infiltration rate on HVAC loads were investigated. The impact of insulation thickness on time to target temperature was then evaluated for transient heating and cooling cases. A model of the LATV was then built in CoolCalc. Heat-up and cool-down simulations were performed for comparison with Oshkosh data. Two cases representing different interior convection correlations and air infiltration rates were evaluated. Model results were similar to the experimental data. The CoolCalc model was delivered to Oshkosh, along with the latest release of the software, to enable continued evaluation of vehicle thermal performance trade-offs and strategies for improving thermal management.

Under the fuel efficiency and performance modeling of medium-duty military vehicles task, NREL worked with Oshkosh to develop and refine a detailed model of a conventional medium-duty military vehicle, as well as multiple HEV powertrain variations. NREL performed simulations of the conventional vehicle in a baseline configuration along with several conventional powertrain cases featuring fuel efficiency enhancements (e.g., alternate engine/transmission/gear ratio selection, reduced accessory loads, etc.). Similarly, NREL simulated the integrated starter generator (ISG), through the road (TTR) and series HEV powertrain configurations over multiple different drive cycles, and summarized for Oshkosh the relative fuel efficiency improvements offered by the conventional powertrain enhancements and by the HEV designs.

Lastly, the design space visualizer was a tool developed by Oshkosh Corporation to perform large-scale trade-studies and simultaneously evaluate different metrics of a system including:

- System performance
- Compatibility
- Cost
- Weight
- Technology Readiness Level
- Production Readiness Level.

NREL completed the tool and interface in Excel to help Oshkosh visualize a design space in which all different combinations (candidates) could be studied along with their metrics. NREL improved the tool by adding the required subtask enhancements:

- Option to change system weighting factors dynamically (through a slider or similar mechanism)
- Option to flag and filter candidates based on certain criteria (specified as a range) *
- Option to sort candidates based on any of its final metrics *
- Display complete performance and impact information about a candidate when requested (as a pop-up or similar mechanism). Highlight incompatible elements *
- Show how component performances add up to system performance when requested (along with system weighting factors that can change dynamically)
- A toggle to look at compatible combinations only or display all combinations*.

NREL also completed many of the additional enhancements including:

- Display complete compatibility information about a candidate when requested (as a pop-up or similar mechanism)
- Provide standard scatter plots to show results. The number of plots and X and Y axes can be predetermined. Contents of the plot should change when filtering
- Implement dynamic sorting. For example, when system weighting factors are changed, the user may choose to see the best performing candidate at the top
- Provide customizable scatter plots to show results. User can select any input or output parameter for X and Y axis
- Implement an option to perform Pareto Optimal filtering
- Provide a graphical tool to choose candidates (rectangular select tool or similar)
- Link the scatter plots – the same set of candidates should be displayed or flagged on all plots
- Display "% of candidates shown" when filtering. This will help keep track of the size of design space the user is currently working on and the size of the entire design space
- Implement current MATLAB functions that are used generate empty Impact and compatibility matrices in Microsoft Excel.

**Subject Inventions Listing**: None

**Report Date**: April 18, 2013

**Responsible Technical Contact at Alliance/NREL**: Matthew Thornton

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