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Working Group Meeting on Heavy Vehicle Aerodynamic Drag: Presentation, Summary of Comments and Conclusions

Jointly written by

Lawrence Livermore National Laboratory, Argonne National Laboratory, Sandia National Laboratories, University of Southern California, California Institute of Technology, Auburn University, University of Tennessee Chattanooga, NASA Ames Research Center, Georgia Tech Research Institute, National Research Council of Canada

U.S. Department of Energy

Lawrence Livermore National Laboratory

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National Research Council of Canada

In Memory

Dr. Sidney ('Sid') Diamond

This document is dedicated to our DOE Program Manager, supporter, and dear friend Dr. Sid Diamond. This Consortium effort would not exist without Sid's vision, dedication, perseverance, and passion. His enthusiasm for this project, with his wonderful gusto for life, was contagious and pushed our effort forward. He will be dearly missed.

A Working Group Meeting on Heavy Vehicle Aerodynamic Drag was held at Lawrence Livermore National Laboratory, Livermore, California on May 12th and 13th of 2005. The purpose of the first day's meeting, May 12th, was to provide a summary of achievements, discuss issues, present a general overview of future plans, and to offer a forum for dialogue with the Department of Energy (DOE) and representatives from industry, universities, and research and development organizations performing work related to heavy vehicle aerodynamics. This first meeting day was open to participants from industry and research organizations from both the US and Canada. The second day, May 13th, was attended only by representatives from the 9 organizations that form the DOE Consortium effort and their government sponsors. The purpose of the second day's meeting was to further discuss fiscal year 2005's activities, any further specific pressing issues, identify individual action items, and provide an overview of plans for fiscal year 2006.

Participating in the Working Group Meeting were representatives from the DOE/Office of Energy Efficiency and Renewable Energy/Office of FreedomCAR & Vehicle Technologies, members of the DOE consortium: Lawrence Livermore National Laboratory (LLNL), Argonne National Laboratory (ANL), Sandia National Laboratories (SNL), NASA Ames Research Center (NASA), University of Southern California (USC), California Institute of Technology (Caltech), University of Tennessee Chattanooga (UTC), (consortium members from Auburn University (Auburn) and Georgia Tech Research Institute (GTRI) were unable to attend), consortium collaborators from the National Research Council (NRC) of Canada, tractor manufacturer representatives: Mack Trucks, Inc./Volvo 3P, International Truck, and Kenworth/PACCAR, a representative from one of the largest national fleets, U.S. Xpress Enterprises, and a tire manufacturer, Michelin R&D, and others from universities, small companies, and other national laboratories. A complete list of participants can be found at the end of this summary section, along with the agendas for both meeting days. This report contains the technical presentations (viewgraphs) delivered each day, briefly summarizes the comments and conclusions, provides some highlighted items, and outlines the future action items.

Project Goals and Future Activities

Based on discussions at the Meeting, the existing project goals remain unchanged and enhancing interactions with fleet owners and operators was emphasized:

- Perform heavy vehicle computations and experiments,
- Validate computations using experimental data,
- Provide design guidance and insight into flow phenomena from experiments and computations, and
- Investigate aero devices with emphasis on collaborative efforts with fleet owners and operators.

The following future activities were identified, categorized as technical or administrative, and the responsible organizations are indicated:

Technical

1. Acquire paper on measure of aerodynamic drag from tire load, SAE 92-0346. (LLNL)
2. Acquire data on duals versus single tires, e.g., SAE II test data from GTRI. (DOE/ANL)
3. Check Kenworth/PACCAR website paper with recommendation on devices (LLNL)
4. Look at "hula" skirts (a flexible, porous device, possibly made of hanging string fibers, mounted on bottom sides of trailer): CFD-porous flexing plate, test- NRC or NASA (LLNL, NASA)
5. Consider benefits for reducing drag for hybrid vehicles. Check findings of large fleets (e.g., UPS). (USC, LLNL)
6. Consider open grate at base of gap (LLNL)
7. Investigate if baseflap and wedge counteract (LLNL)
8. Investigate if flow can be excited to improve baseflaps and effect of different flap angles (LLNL)
9. Investigate splash and spray with baseflaps and if visibility of brake lights could be hindered (LLNL)
10. Evaluate singularity points on rotating tire (UTC)
11. SAE Conference Chicago in Nov 2005 – Papers/abstracts/presentations (ALL), Invite as Consortium/National Lab representative on Aero Panel (LLNL/Kambiz S.), Invite as LLNL representative on Technology Panel (LLNL/Rose M.)

Administrative

1. Gather all viewgraphs from meeting (ALL send to LLNL)
2. Meeting with fleet owners, ATA, and others, possibly at SAE Conference, Chicago, Nov 2005 (LLNL – SOLUS is now coordinating meeting)
3. Contribute to 21CTP white paper on aero (LLNL)
4. Attend, present at 21 CTP aero merit review possibly in September (LLNL)
5. Join US Xpress Enterprises representative, Marty Fletcher, at an ATA, TMC, or TMA committee meeting (LLNL)
6. Sharing of DOE industry Consortium test plan (DOE)
7. Construct industry collaborative proposals to DOE's 2007 RFP (ALL)
8. Address underhood cooling with aero-white paper or possible CRADA (NASA, LLNL, ANL)
9. Pursue joint government (DOE, DOT) and industry (Michelin) effort on wheel aero and splash & spray (USC, LLNL)
10. Industry incentives – talk to 21CTP Lead, Ken Howden (DOE)
11. Visit other big fleet operators, Fedex, UPS (LLNL, USC, NASA, UTC)

12. Find product engineers who can design devices or decide if need national labs to design (LLNL)
13. Ask NRC to test effectiveness of devices for braking (LLNL)
14. Meet with rail companies, railcar manufacturers, power companies (NASA)
15. Meeting with DOT & Bill Knee, ATA's Vic Suski (DOE)
16. Construct FY06 tasks/milestones and budget by mid July, determining high priority activities, considering expected budget cuts (LLNL).
17. Suggest people for ECI meeting to Dave Whitfield, UTC (ALL)

Meeting Summary

In this section, we briefly review the major results presented and discussed at the meeting, with a focus on new information not previously presented. See meeting agendas at the end of this section and attached viewgraphs for additional results and details.

Introduction

The meeting began with an introduction by the DOE Aero Consortium Lead, Rose McCallen (LLNL) and a welcome from LLNL's Energy Program Lead, Ray Smith (LLNL). LLNL's Associate Director, Jane Long, also provided a brief description of the Energy & Environment Directorate and a welcome to the meeting participants during Lunch. The DOE sponsor, Sidney Diamond (DOE), followed the introductions. Sid first mentioned that the DOE Consortium was formed 7 years ago at the first workshop held in Pheonix, Arizona to address aerodynamic drag of heavy truck vehicles. He also emphasized the benefits to reducing fuel consumption by heavy vehicles. Class 8 tractor-trailers consume 11% to 12% of the total U.S. consumption of petroleum.[1]

Jules Routbort (DOE/ANL) presented an overview of the 21st Century Truck Program for Ken Howden (DOE) who was unable to attend. Mike Laughlin (New West Technologies) also gave an overview of the activities of the newly formed DOE Industry Consortium for Bob Clark (TMA) who was unable to attend. The DOE Industry Consortium consists of Freightliner, International, Mack Trucks, and Volvo. They are investigating four major areas of Class 8 tractor-trailer drag reduction. Mike also provided some information on the Department of Transportation Re-Organization and the formation of the new Research Innovation Technology Administration (RITA) formed as part of the re-organization.

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[1] Per 2002 statistics in U.S. Department of Energy, Oak Ridge National Laboratory, Transportation Energy Data Book, 24th Edition (http://cta.ornl.gov/data/new_for_edition24.shtml), tractor-trailer combination vehicles drive 138.6 billion miles per year and consume 26 billion gallons of diesel fuel per year. If we assume that the refinement of a barrel of crude oil, provides about 70-80 percent diesel fuel, then the tractor-trailer crude oil consumption is 2.1 to 2.4 to million barrels per day (= 26 billion gal (1 barrel/42 gal) (1 yr/365 days) (1 barrel crude/0.7 to 0.8 barrel diesel)). The total US crude oil consumption is about 19.7 million barrels per day.

After these introductory and background presentations, an overview of the DOE Heavy Vehicle Aero Project and the Consortium's goals, objectives, and focus areas past, present, and planned for the future was presented by Rose McCallen (LLNL). This introduced the main part of the meeting consisting of three presentations to introduce the 3 topics for discussion:

- Achievements,
- Main issues, and
- Path forward.

Informal discussions followed each presentation (see agenda at end of this report, before the viewgraphs). Summaries of the discussion for all three topics were presented so that conclusions may be established. The highlights of the discussions are presented below and details are provided in the attached summary viewgraphs.

Also, during the working lunch, movie presentations were given on "Tire Aero & Splash/Spray" by Michelin Tire representative, Ralph Hulseman, and on a "Baseflap Device" by Norcan representative, Mathieu Boivin.

Achievements

Attached are the viewgraphs presented by Kambiz Salari (LLNL), providing an overview of the Program accomplishments. In summary, the Program has demonstrated several concepts and devices which meet the 25% drag reduction goal. Specific devices have addressed base, gap, and underbody drag reduction (Figure 1). Use of a simple base flap at the trailing edge of the trailer, side extenders or splitter plate at the tractor-trailer gap, and a skirt or a simple short underbody wedge should provide drag reduction exceeding 25%. At highway speeds, fuel savings around 12% should be recognized for a 25% reduction in drag. This would represent savings in the billions of dollars in the United States.

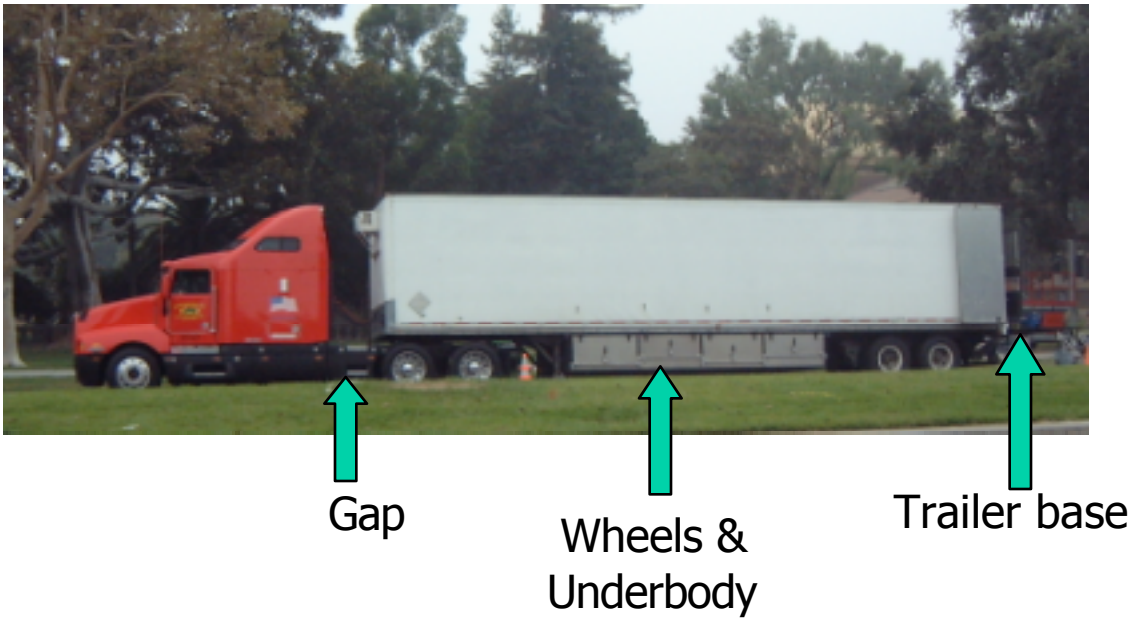

Figure 1. The major drag contributors are the trailer base, underbody, and gap drag.

The Consortium's highly successful testing program has provided detailed data for computational validation, guidance on device concepts, and established wind-tunnel testing guidelines. The computational flow modeling has provided guidance in model definition, mesh refinement, and choice of turbulence model for heavy vehicles. Computations have been used for both the evaluation of flow physics and to guide the conceptual design of devices. The Program has successfully established industry contacts and collaborations and international recognition in the academic community.

The presentation of achievements was followed by a discussion session facilitated by Dave Whitfield (UTC). Viewgraphs summarizing the discussion were constructed and presented by Mike Rubel (Caltech) and John Paschkewitz (LLNL). The main discussion points included:

- NRC Canada has explored many of the presented device concepts and has performed full-scale testing. The Consortium should continue their pursuit of collaborative efforts with NRC.
- The Consortium needs to involve industry sooner in process to consider practical constraints, but at the same time should be forward-looking about technology changes. The participant from US Xpress Enterprises, Marty Fletcher, emphasized that the end user does dictate what devices are used and must consider maintenance, liability, and other issues. Operation issues include how individual devices for gap, underbody, and base interact. One suggested source of information is the American Trucking Association's (ATA) advisory group which

consists of fleet operators. The need to put information out to the masses and presented for the general audience was emphasized.

- Underhood/thermal control needs to be considered, especially with upcoming 2007 EPA emissions regulations. Difficulty is lack of experimental data.
- Should report ΔCD as well as percent drag reduction, since base drag is so variable.
- Model fidelity is important. Flow through radiators should be considered in experiments and computations.

Main Issues

Attached are the viewgraphs presented by Jim Ross (NASA), providing a summary of the program's current, main issues for discussion. Tony Leonard (Caltech) facilitated the discussion and attached are the summary viewgraphs constructed and presented by Ramesh Pankajakshan (UTC) and Paul Castellucci (LLNL).

In summary, the specific topic areas presented were:

- Getting improvements on the road,
- Aerodynamic prediction capability, and
- Funding.

The following summarizes the opinions of the participants as to why the fleet owners and operators are not using the trailer devices and what can be done to encourage the use of drag reducing technology. Also included are some important points made during the discussion regarding computational and experimental predictive capability and funding.

Devices

- Engineering and marketing of devices is needed for immediate impact. Devices should be transferable and reusable.
- Data on device performance isn't readily available.
- There is an industry disconnect. For example, the trailer manufacturers are absent from the discussion/meetings.
- The operational restrictions that limit device use are needed. For example, could base flaps restrict brake light visibility and trailer access?
- Information on what has been tried and economic benefits is needed.
- It is unclear why the manufacturing industries have not integrated the tractor and trailer system.
- It is believed that rising fuel prices will force the issue.
- The Consortium needs to do more in sharing their R&D information with industry and getting the information in the public domain. For example, simple messages like don't go faster and don't idle if you want to reduce your fuel consumption.

Predictive Capability

- Reliability of computational fluid dynamics (CFD) is longer term.
- Keeping track of winds is important in comparing wind tunnel and road tests.
- The effect of a moving ground plan on the vortical structures and the forces and moments should be investigated.
- Considering open grill is critical for drag simulations and experiments. The effect of the open grill is important if trying to manage flow. For example, in the design of an aerodynamic bumper.

Funding

- DOE Collaborative Research and Development Agreements (CRADA) funding generally goes to the National Labs for collaboration with industry. Proprietary information can be protected in a CRADA.
- DOT may have interest in splash and spray
- OEM's and tire manufacturers don't get credit for reducing fuel consumption. For example, the EPA could provide credit for the associated reduction in emissions.
- DOE should encourage EPA's SmartWay Program to give credit for fleet operators using drag reducing devices.

Path Forward

Attached are the viewgraphs presented by Rose McCallen (LLNL), providing a brief summary of the program's "Path Forward". Also presented was a review of "Wheel Aero/Safety/Underhood – Drag, Brake Cooling & Splash/Spray" by Craig Eastwood (LLNL) and Fred Browand (USC), followed by a presentation of NRC Canada's work and future collaboration presented by Kevin Cooper (NRC) and Jason Leuschen (NRC). Larry DeChant (SNL) facilitated the discussion that followed the presentations. David Pointer (ANL) and Jason Ortega (LLNL) constructed and presented a summary of the discussion. All the viewgraphs are included at the end of this document.

The following are the five suggested future focus areas with a brief description.

Getting technology on the road: This will involve working with fleet operators, tractor manufacturers, especially those involved in the DOE Industry Consortium, and trailer manufacturers to encourage full-scale road testing of promising devices. These activities should be in collaboration with the full-scale testing being done at NRC Canada.

System integration: With the recognition of the ties between vehicle aerodynamics and safety issues related to brake cooling and tire/wheel splash and spray, joint DOE/DOT government activities will be pursued. The goal is reducing fuel use with enhanced safety.

Computational modeling that adequately captures reality: The computational modeling effort will pursue needed improvements in model scaling and fidelity, multi-physics modeling, and consideration of operational environment.

New areas: Tire/wheel aerodynamics with the investigation of brake cooling and splash and spray will be investigated both computationally and experimentally. Use of state-of-the-art computational tools and experimental diagnostics will be used to further the understanding of underhood thermal control, leading to conceptual design improvements. Support for continued investigations of railcar aerodynamics will also be pursued.

Funding: Attempts will be made to expand funding sources through government teaming and leveraging of funds.

The session on Wheel Aero/Safety/Underhood included presentations delivered by Craig Eastwood (LLNL) and Fred Browand (USC). Craig provided an overview of the computational work being performed at LLNL, UTC, and Caltech. Simulations of rotating wheels with increasing fidelity, splash models, and spray simulations around a truck model were described. The aerodynamics of rotating wheels is being considered not only for underbody aerodynamic drag, but also for the modeling of brake cooling and splash and spray. Preliminary splash simulations have been performed utilizing a volume-of-fluid surface tracking algorithm. Ongoing work involves the goal of simulating spray around an entire truck model include aerodynamic breakup, collisions, and preferential concentration effect. The success of the effort is dependent in part on the high-quality experimental data being provided by USC for both benchmarking and validation of the computational models, as well as the physical insight provided directly from the analysis of the experimental data.

As part of this same session, Fred Browand (USC) presented a detailed theoretical analysis of jet, sheet, and droplet formation for rotating tires. He showed some remarkable visualizations of jet, sheeting, and droplet formation and breakup. The results were from experiments being performed at USC with a new apparatus called the Tire Spray Simulator (TSS). The TSS has demonstrated its usefulness in creating realistic spray. Qualitative results have been obtained using a backlight and laser sheet procedures, leading to an understanding of some the mechanisms behind the formation of jets and sheets, and of the eventual formation of droplets. The next step in analysis will be to measure droplet size and droplet velocity as a function of position within the spray field. Droplet sizes within the spray field are of first importance in themselves, but size information is also needed to resolve the velocity field according to size. Plans are to evaluate droplet size in each image pair and filtering each image before the digital particle image velocimetry (DPIV) algorithms are applied. Local droplet size or local scale can be determined either by application of an image-segmenting technique or by application of a localized scale-filtering process such as a wavelet transform.

Also presented was a preliminary design idea by Consortium members from NASA for a 'separate flows for separate tasks' underhood flow/thermal control configuration. The design is inspired by the design of a Lancair 320 aircraft. The plans for a heavy vehicle engine is to provide separate air passages for radiator cooling air and for cooling of specific accessories. The proposed diagnostics include measured pressures throughout the engine compartment, use of temperature-sensitive paint for temperature measurement, and DPIV for velocity field information.

Representatives from NRC, Kevin Cooper and Jason Lueschen, described their collaborative experimental wind tunnel work. It was emphasized that their effort is a "non-competitive, non-commercial program" that is "not intended to invent products" but is instead "designed to transfer technology to benefit truckers & country." NRC is aligning their work with the DOE program to leverage the investment by their funding source, National Resources Canada. The goal is to test common hardware, exchange wind tunnel and road data, share hardware where possible, and interface with OEMs. Their current wind tunnel results show that trailer skirts, trailer base mounted boattails, and tractor side extenders are the most promising.

Overview of Second Day

The presentations on the second day, May 13th, provide more detailed, technical information on topics including drag reducing concepts, with related safety enhancements. Also included were presentation summarizing conclusions from the first day meeting and future activities.

Truck Aero Team Meeting Attendees

Lawrence Livermore National Laboratory, Livermore, CA

May 12, 2005

Attendee	Organization	e-mail address and phone
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Rick Wood	SOLUS LLC	rick@solusinc.com

AGENDA

Heavy Vehicle Aerodynamic Drag: Working Group Meeting

Lawrence Livermore National Laboratory, Livermore, CA

B170, Rm 1091 & 1092

May 12, 2004

Purpose of Meeting

Sharing of information & discussion of issues to define our path forward

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Introduction		
7:45—8:15AM	Continental Breakfast	
8:15—8:30AM	Introduction, safety, security	Rose McCallen (LLNL)
8:30—8:45AM	Welcome to LLNL	Ray Smith (LLNL)
8:45—9:00AM	Words of Wisdom	Sid Diamond (DOE)
9:00—9:15AM	21st Century Truck Program	Jules Routbort for Ken Howden (DOE)
9:15—9:30AM	DOE Industry Consortium	Mike Laughlin for Bob Clarke (TMA)
9:30—9:45AM	Re-org: Research Innovation Technology Administration	K. Thirumalai (DOT)
9:45—10:00AM	**DOE Heavy Vehicle Aero Project** - Overview	Rose McCallen (LLNL)
10:00— 10:15AM	**Break** (15 min)	
Achievements		
10:15— 10:45AM	Exp. & Comp. Directed Drag Reduction Devices (30 min)	Kambiz Salari (LLNL)
10:45— 11:15AM	Facilitated Discussion (30 min) – informal	Dave Whitfield (UTC)
11:15— 11:30AM	**Break** (15 min)	
11:30— 11:45AM	Summary (15 min)	Mike Rubel (Caltech), John Paschkewitz (LLNL)
Main Issues		
11:45— 12:00PM	Presentation of Issues (15 min)	Jim Ross (NASA)
12:00— 12:30PM	Facilitated Discussion (30 min) – informal	Tony Leonard (Caltech)
12:30— 1:45PM	**Lunch** (45 min)	
	Tire Aero & Splash/Spray Movies (15 min)	Ralph Hulseman (Michelin)
	Baseflap Device	Mathieu Boivin (Norcan)
	LLNL's Energy & Environment Directorate	Jane Long (LLNL's Associate Driector)
1:45— 2:00PM	Summary (15 min)	Ramesh Pankajakshan (UTC), Paul Castellucci (LLNL)
Path Forward		
2:00— 2:15PM	Presentation on Path Forward (15 min)	Rose McCallen (LLNL)
2:15—2:45PM	Wheel Aero/Safety/Underhood – Drag, Brake Cooling & Splash/Spray	
	Computations – LLNL, UTC, Caltech (15 min)	Craig Eastwood (LLNL)
	Experiments – USC (15 min)	Fred Browand (USC)

2:45—3:00PM	Collaborations with Canada (15 min)	Kevin Cooper (NRC), Jason Leuschen (NRC)
3:00— 3:30PM	Facilitated Discussion (30 min) – informal	Larry DeChant (SNL)
3:30—3:45PM	**Break** (15 min)	
3:45—4:00PM	Summary (15 min)	David Pointer (ANL), Jason Ortega (LLNL)
6:00—7:00PM	**Dinner (no-host) – Pastas Trattoria, 4040 East Ave, Livermore**	
7:00—7:15PM	Discussion, wrap-up	Sid Diamond (DOE), Rose McCallen (LLNL)

AGENDA

Heavy Vehicle Aerodynamic Drag: Working Group Meeting

Lawrence Livermore National Laboratory, Livermore, CA

B543, Grand Canyon Room

May 13, 2004

Purpose of Meeting

1. Discuss activities, pressing issues
2. Overview of FY06 plans, budget

Introduction

8:00—8:30AM	Continental breakfast	
8:30—9:00AM	Review of key items from previous day (30 min)	Fred Browand (USC)/Craig Eastwood (LLNL)
9:00—9:30AM	Discussion on previous day – facilitated (30 min)	Jim Ross (NASA)

Current FY05 Activities & Pressing Issues (~15 min presentations, ~15 min discussion)

9:30—9:40AM	Introduction & Objective (10 min)	Rose McCallen (LLNL)
9:40—10:30AM	HV Devices (50 min)	Jason Ortega/Paul Castellucci (LLNL)
10:30— 10:45AM	**Break**	
10:45— 11:15AM	Other Devices (30 min)	Bruce Storms (NASA)
11:15— 12:00PM	Safety – Splash & spray, brake cooling (45 min)	Ramesh Pankajakshan (UTC)/John Paschkewitz (LLNL)
12:00— 1:30PM		**Lunch (1 hr)**

Wrap-up

1:30— 3:30PM	Summary of action items, wrap-up (1 hr)	All