Project ID# eems065
Pillar(s) : CAVs

U.S. DEPARTMENT OF ENERGY
SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

Analysis of Platooning Trucks to Better Understand Dynamic Air Flow

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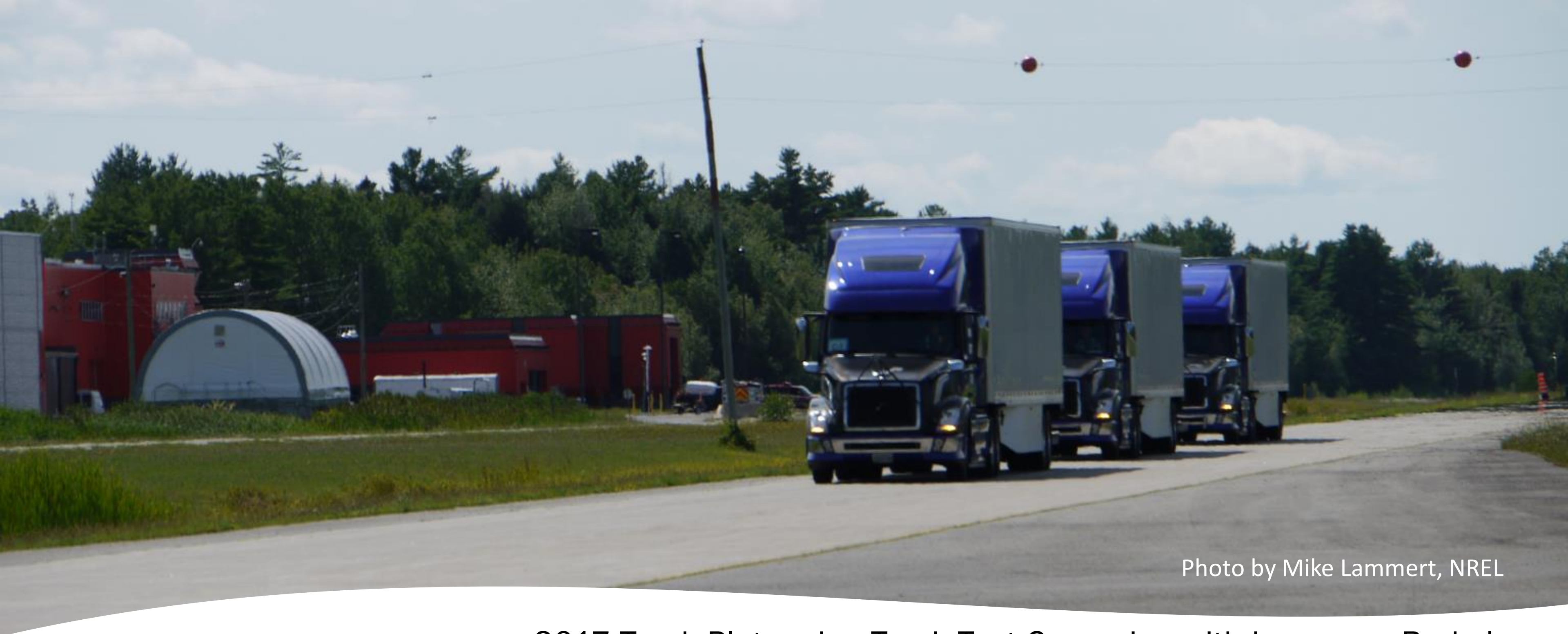
National Renewable Energy Laboratory (NREL)
2019 Vehicle Technologies Office Annual Merit Review
June 11, 2019

Argonne National Laboratory | Idaho National Laboratory | Berkeley Lab | Oak Ridge National Laboratory | NREL National Renewable Energy Laboratory



OVERVIEW

- 2017 Truck Platooning Track Test Campaign with Lawrence Berkeley National Laboratory (LBNL), Transport Canada and National Resource Council (NRC) Canada
  – 26 two- and three-truck platooning scenarios investigated
  – Tested aerodynamic sleeper cabs, side skirts, and trailer tails SAE J1321 gravimetric fuel measurement procedures
  – J1939 data collection and external sensors
  – Paper published at SAE World Congress Experience April 2018 with LBNL and NRC -- "Influences on Energy Savings of Heavy Trucks Using Cooperative Adaptive Cruise Control"
  https://www.nrel.gov/docs/fy18osti/70868.pdf


Photo by Mike Lammert, NREL

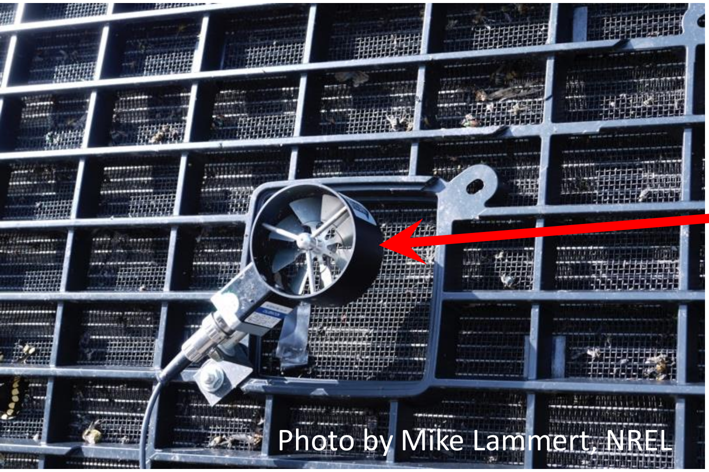


Photo by Mike Lammert, NREL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OVERVIEW

- 2017 track test included numerous additional onboard instrumentation not analyzed in primary paper
  - J1939 CANBUS native data stream capture
  - Cobra Probe mounted 1 meter ahead of vehicle 2 meters off the ground
    - Three-component velocity and local static pressure
    - Ambient thermocouple
  - Air velocity transmitter mounted flush to center of grill
    - Velocity and temperature
  - Six thermocouple grid attached under hood with air gap to surface
- Fiscal Year (FY) 19 activity to analyze the collected data

***** Post processing of onboard sensors just completed late in February 2019 by NRC Canada – Delayed NREL's analysis start *****

OVERVIEW

Timeline

- Project start date: 10/01/18
- Project end date: 09/30/19
- Percent complete 10%

Budget

- Total project funding: $90K
  - DOE share: $90K
  - Contractor share: $
- Funding for FY 2019: $90K

Barriers

- Barriers addressed
  - Vehicle Systems Analysis Technical Team barrier of maintaining up-to-date vehicle performance models and developing appropriate test procedures for new technologies such as platooning

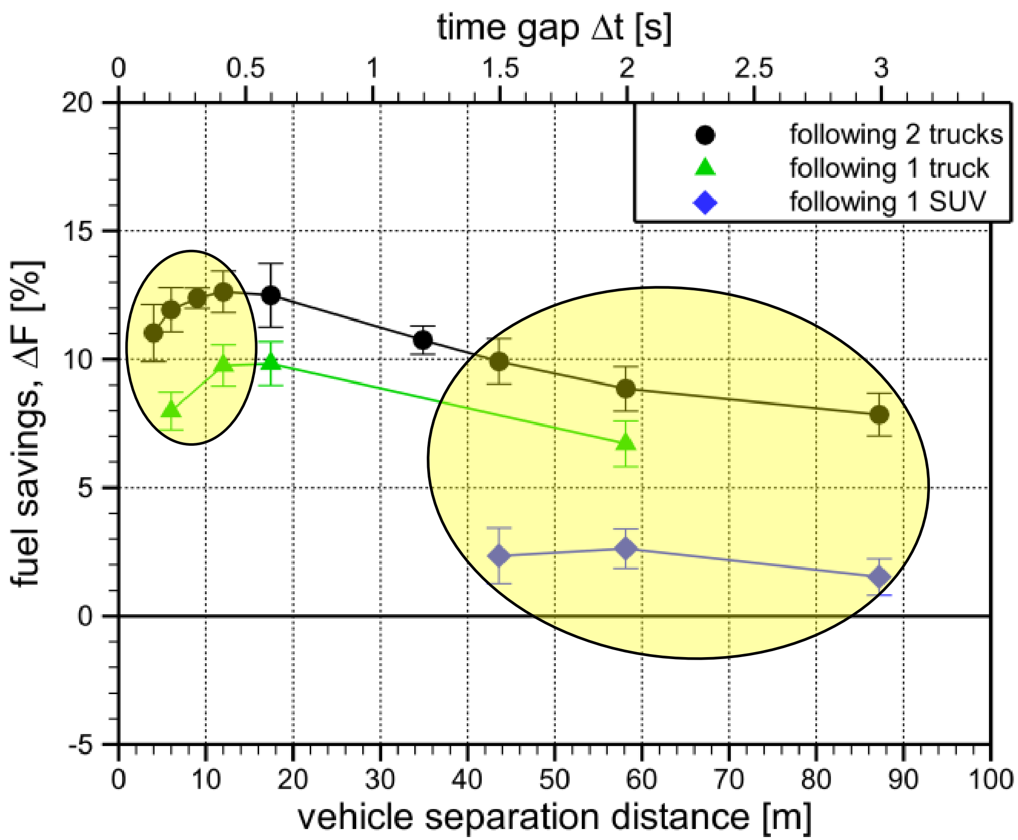
Partners

- LBNL, Transport Canada and NRC Canada
- LBNL Project lead

RELEVANCE

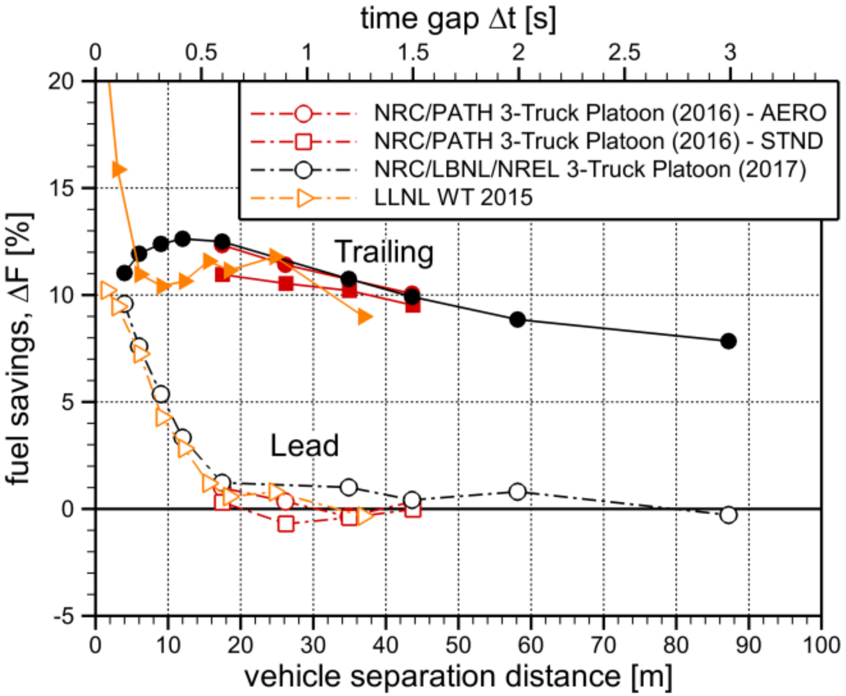
- 2018 SAE World Congress paper extended knowledge of platooning savings and confirmed significant questions around truck platooning's real-world savings potential
  - Unexpected reduced-trailing-truck savings at close following distances of 4-12 meters (limits team savings)
  - "Background platooning" from other traffic (could change the baseline to measure from)
    - 5-9% trailing-truck savings at distances of 44−87 meters behind tractor trailer
    - 2% individual-truck savings following compact sport utility vehicle (SUV) at distances of 44−87 meters
  - Both could have significant real-world impacts and need to be better understood
  - **Impacts to real-world fuel savings will impact industry adoption rate**

Truck Following Scenario Energy Savings



APPROACH

- Detailed data analysis for additional onboard sensors and J1939 CANBUS data from 2017 track test
  - Investigate following truck air flow and turbulence changes to explain reduced savings at close following distances for the last vehicle in a platoon
  - Define engine-cooling impacts of platooning position in different formations due to reduction of ram air through front grill
  - Generate an understanding of a true in-use “baseline” with other vehicles on the highway
  - Correlate track test data with Lawrence Livermore National Laboratory wind tunnel wind average drag coefficient, pressure and particle image velocimetry data

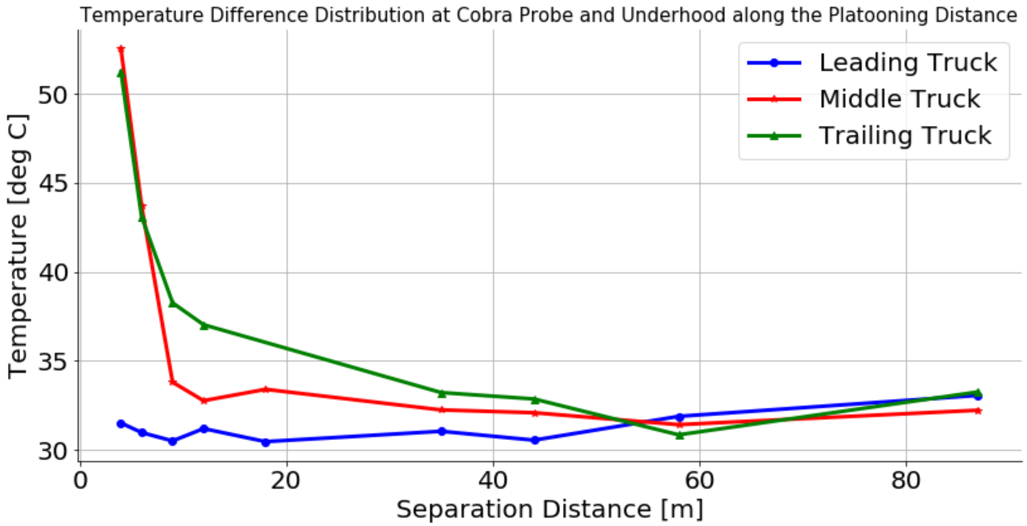


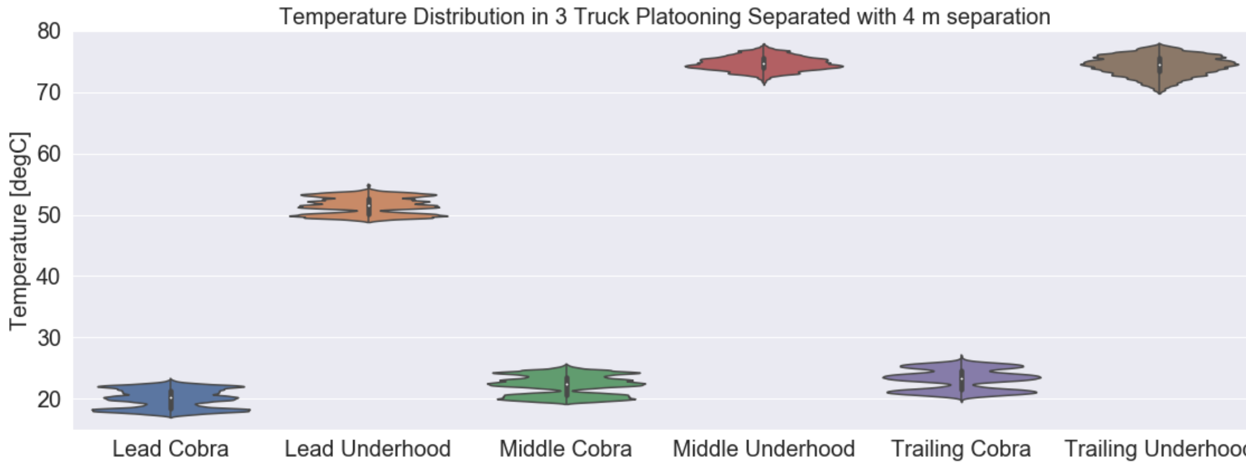
MILESTONES

CAVs 3.1.1: Milestone Name/Description	Criteria	End Date	Type
CAVs 3.1.1: Q4: CACC truck air-flow test data analysis results; the data was obtained at Transport Canada Test Track (NREL)	• Report on data analysis results of air-flow effect on aerodynamic drag and engine temperature	9/30/2019	Annual (Regular)

TECHNICAL ACCOMPLISHMENTS: AIR TEMPERATURE ANALYSIS

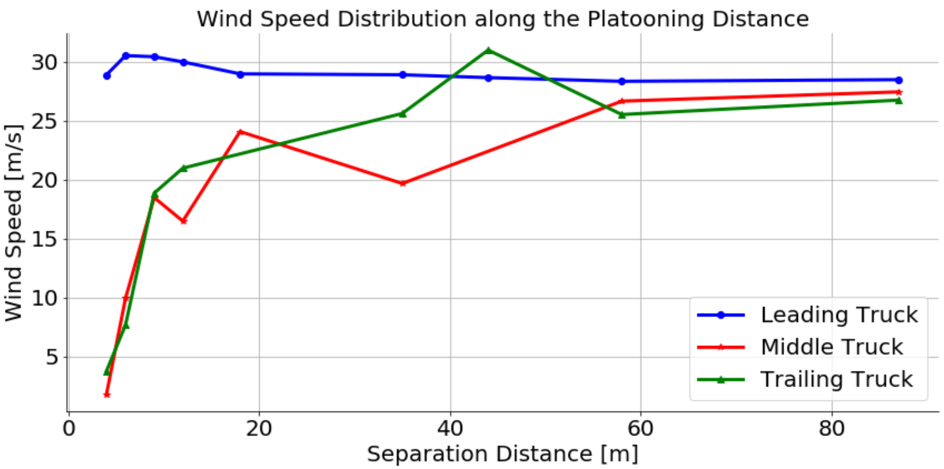
- The temperature rise on middle and trailing trucks from the Cobra Probe to under-hood thermocouple grid is significantly impacted at less than 18 m but is quite similar to lead truck by 35 m
- Middle and trailing trucks have slightly elevated air temperature at the Cobra Probe than the lead truck at close following distances
- Violin plots of temperature data show the range and probability density of the data distribution

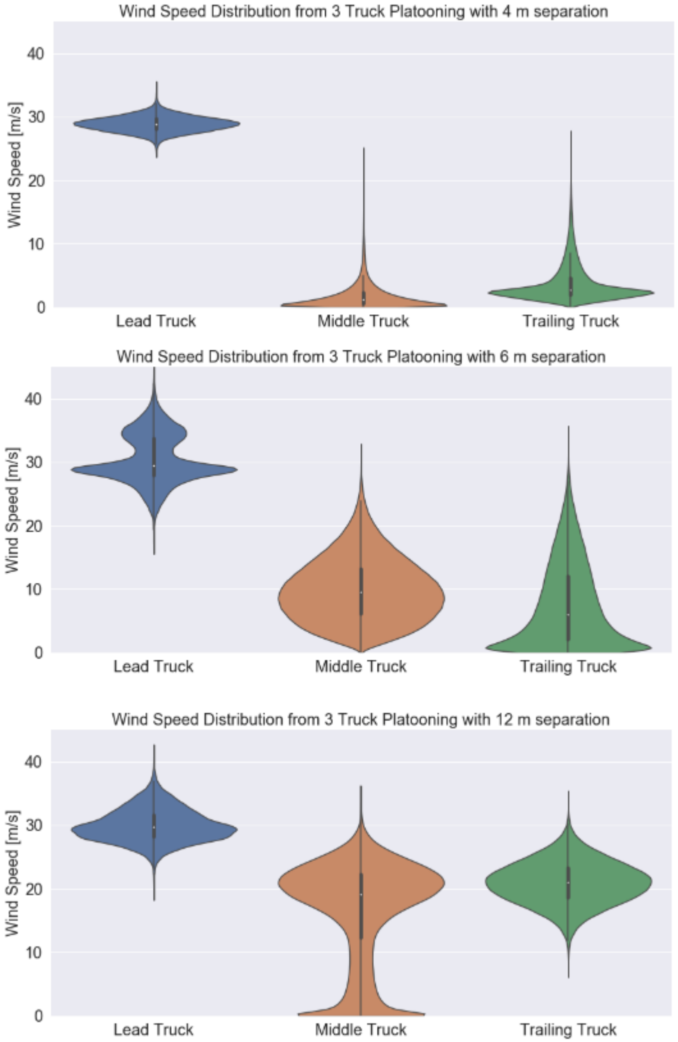




TECHNICAL ACCOMPLISHMENTS: WIND SPEED ANALYSIS

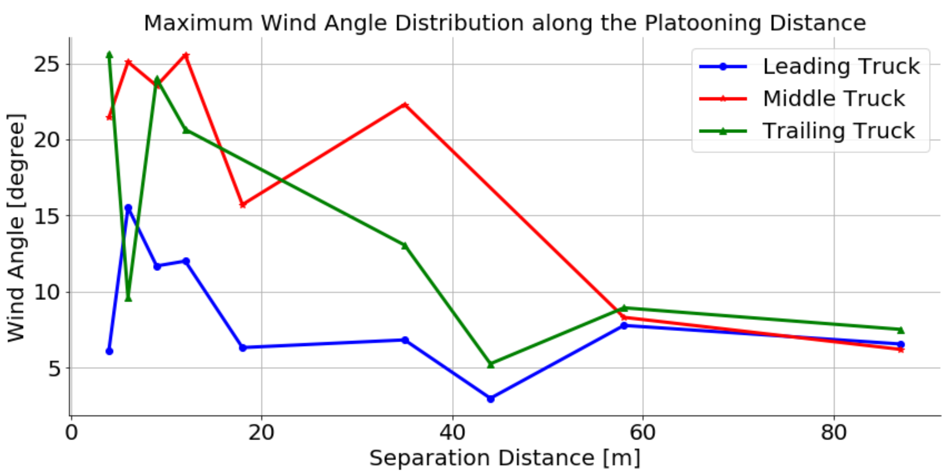
- Measured wind speeds from the Cobra Probe for the middle and trailing trucks are significantly lower than the front truck with gap distances less than 18 m and does not approach consistency with lead truck until 58 m
- Following trucks also have higher variability in wind speed out to 58 m
- Violin plots demonstrate the lower wind speed and higher variability experienced by the following trucks at 6 and 12 meters and extremely low wind speeds at 4 meter separation
  – This is a first step in quantifying turbulence





TECHNICAL ACCOMPLISHMENTS: WIND-ANGLE ANALYSIS

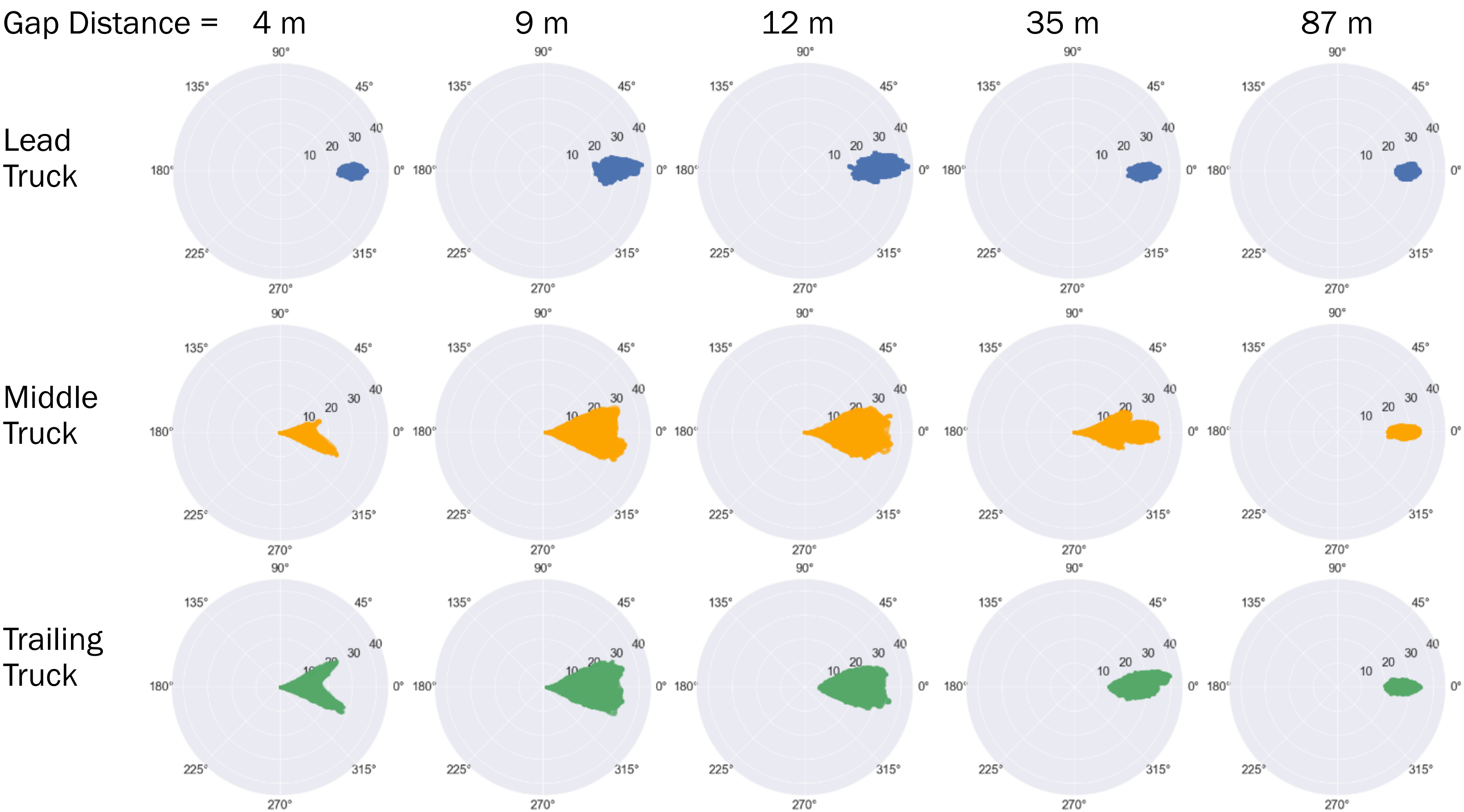
- Measured wind angles from the Cobra Probe for the middle and trailing trucks have significantly more variation and higher angles than the front truck with gap distances of 35 m and less and does not approach consistency with lead truck until 58−87 m
  - Experiencing wind 20 degrees off center has an aerodynamic impact that must be assessed
- Violin plots demonstrate the higher wind angle variability experienced by the following trucks at 6 and 12 meters and to a lesser extent at 4 meter separation
  - This is a first step in quantifying turbulence



TECHNICAL ACCOMPLISHMENTS : COBRA PROBE - WIND SPEED AND DIRECTION

- The following slide shows wind speed and direction for all three trucks at five of the eight tested distances. (Data for all points are available, except 44 m on the middle truck and 18 m on the trailing truck when there were instrumentation failures, but all distances could not fit this format)
  - These plots describe the 2D wind velocity and angle experienced by each truck as if you were looking down on the truck with its bumper at the center point and the vehicle facing right.
  - Distance from the center point indicates higher measured wind speed of the point
  - Points off the 0 degree line indicate the wind angle the vehicle is experiencing
- This combined wind speed and angle information will be explored further to quantify the turbulence experienced, especially at closer distances where followers save less than expected.
  - The loss of savings by followers at close following distances correlates with the higher wind angle and lower wind speed measurements indicating turbulence may be playing a roll in the reduced savings

TECHNICAL ACCOMPLISHMENTS : COBRA PROBE - WIND SPEED AND DIRECTION



RESPONSES TO PREVIOUS YEARS REVIEWERS' COMMENTS

- As this was a new task this year there were no reviewer comments last year to respond to.

COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS

The track testing series that generated this data was a multi-lab, multi-national collaboration, including:

- Lawrence Berkeley National Laboratory
- National Resource Council Canada
- Transport Canada
- Volvo Group
- FPInnovations

The sensor data were analyzed in coordination with:

- Lawrence Berkeley National Laboratory
- National Resource Council Canada

REMAINING CHALLENGES AND BARRIERS

Detailed analysis of the onboard sensors has been underway for less than a month and only the basic, straightforward scenarios have begun to be addressed. Additional areas of investigation planned for FY19 include:

- Cobra probe wind angle and velocity high-speed fluctuation analysis to help quantify turbulence.
- Analysis of dynamic vehicle scenarios and those involving light-duty vehicles
- Combination analysis linking J1939 data with onboard sensor data (i.e., coolant and oil temperature with under hood temperatures and air flow variables)

PROPOSED FUTURE RESEARCH

Beyond FY19

- The breadth, depth and diversity of this high resolution data may lend itself to analysis utilizing NREL's HPC and machine learning techniques. The current analysis effort may discover correlations that necessitate HPC and machine learning to fully understand.
- This data set could also prove very valuable for validating a next generation computational fluid dynamics model for simulating turbulent flows within a truck platoon by building on NREL's Exascale Computing Project that developed Nalu-wind which simulated turbulent flows within a wind farm.

Any proposed future work is subject to change based on funding levels.

SUMMARY

Track testing has shown significant fuel-savings promise for truck platooning strategies but also raised unexpected questions about close following and long-distance following scenarios that could significantly impact savings realized in real-world conditions. The 2017 track test collaboration among NREL and LBNL, NRC Canada, Transport Canada, and others included onboard instrumentation to help the team gain a deeper understanding of the dynamic interaction between multiple vehicles. Because of the significant effort required to correct and calibrate some of these sensors to track-side sensors, NREL was only able to begin an analysis effort on the full sensor suite in March 2019.

Initial data analysis indicates many of the data trends in wind angle, wind speed, and temperatures show a change in pattern for the closer following distances where fuel savings decrease for the following vehicles was also documented. This is encouraging in that the planned further analysis may yield the desired insights into the cause of the reduced savings. Once analyzed, light-duty vehicle and dynamic scenarios will help us refine the sensitivity of findings from the standard platooning scenarios.

QUESTIONS?