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# Real World Brake Activity of Heavy-Duty Vehicles

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# Real World Brake Activity of Heavy-Duty Vehicles



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## Project Motivation

Non-tailpipe PM emissions become the primary focus as tailpipe emissions are reduced through implemented regulation.

Brake wear emissions depend on brake pad material, vehicle category, and driving patterns.



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## Background

The California Air Resources Board Emission FACtors model (EMFAC) assess emissions from on-road vehicles using both laboratory testing and near road environments.



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## In this study:

A heavy-duty vehicle brake activity is assessed based on vehicle vocation by using both chassis dynamometer testing and on-road testing.

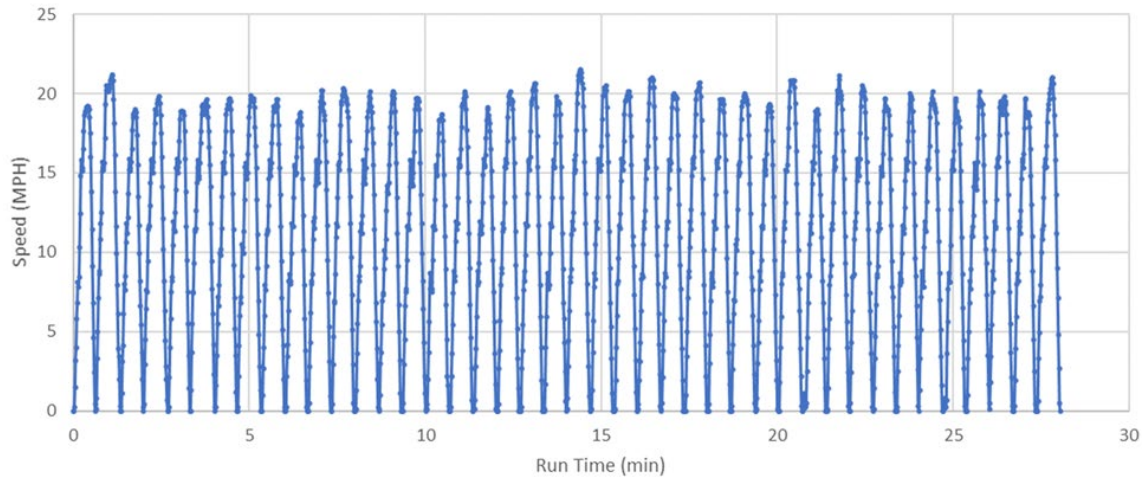
# Project Overview

## Chassis Dyno Tests

The brake activity quantified: brake temperature, brake fluid pressure, vehicle speed, vehicle position and elevation, and ambient conditions.

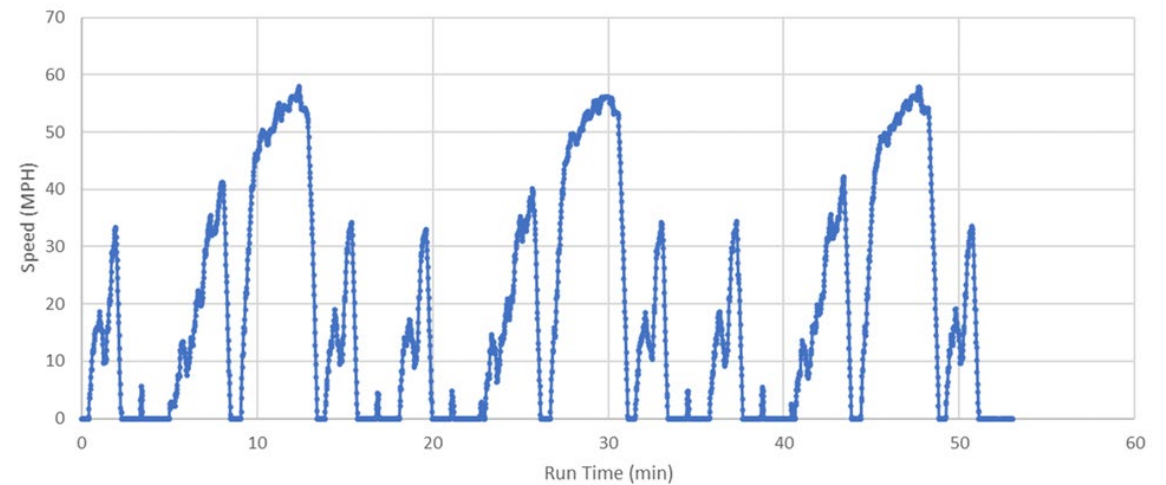
### Central Business District (CBD) cycle

representative of a city bus or transportation vehicle driving patterns.



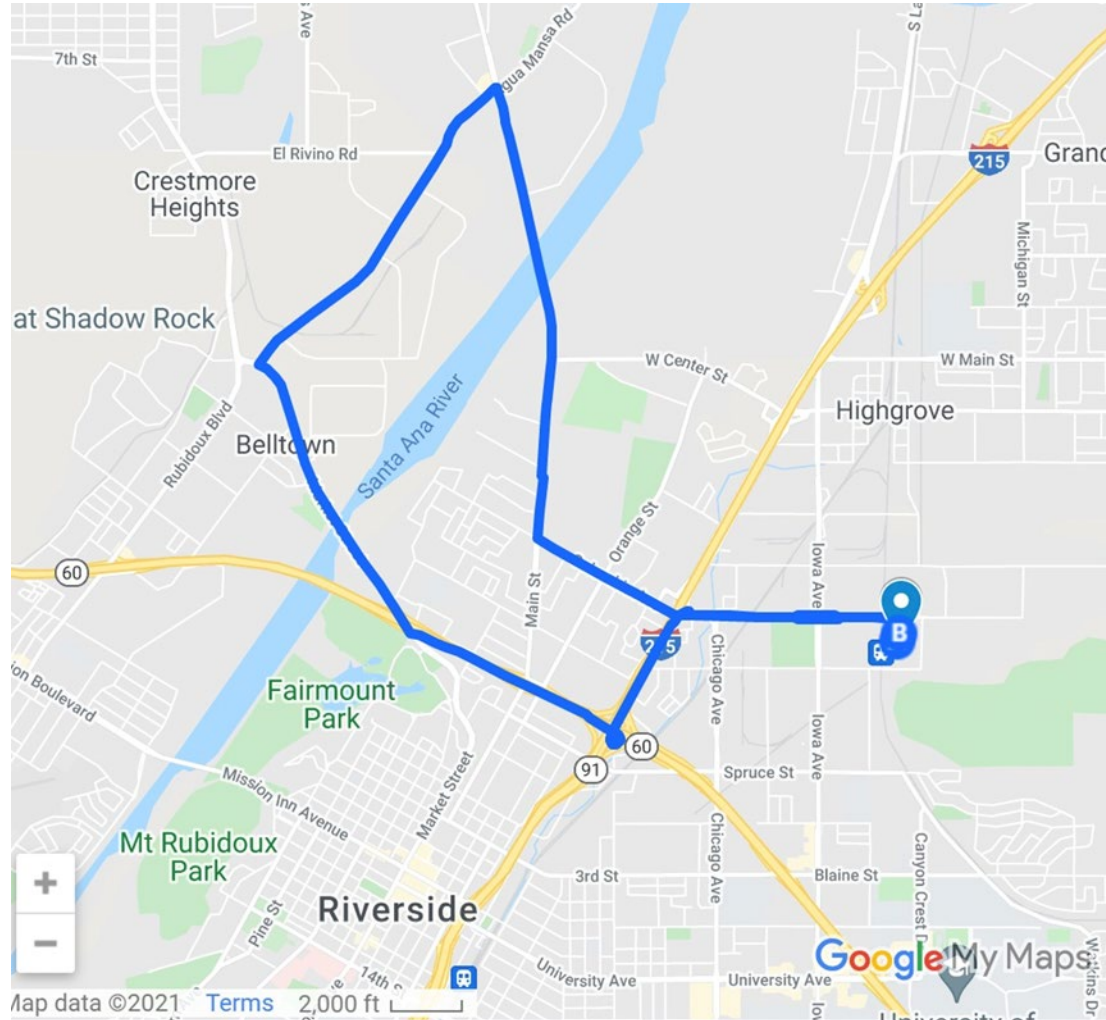
### Urban Dynamometer Driving Schedule (UDDS) Cycle

Representative of heavy-duty vehicle urban driving conditions

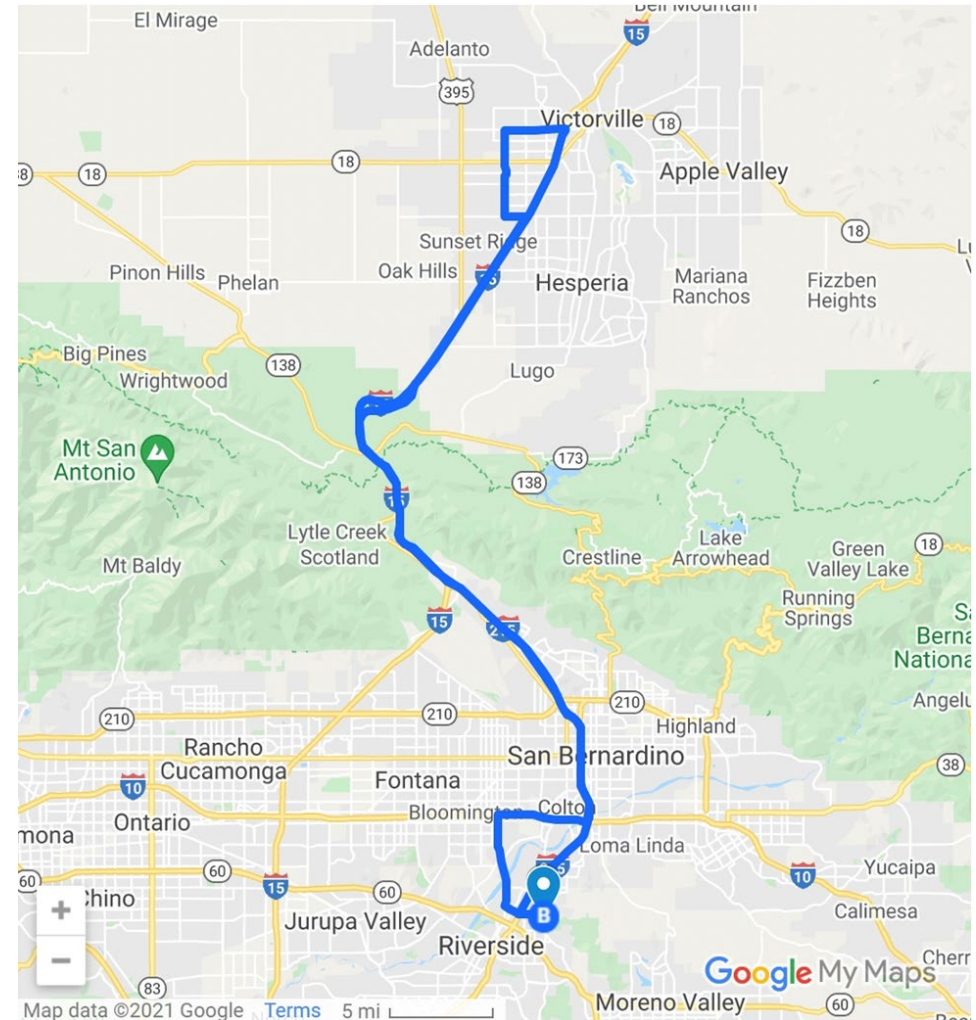


# Project Overview

## On-Road Tests



Local Riverside City Route



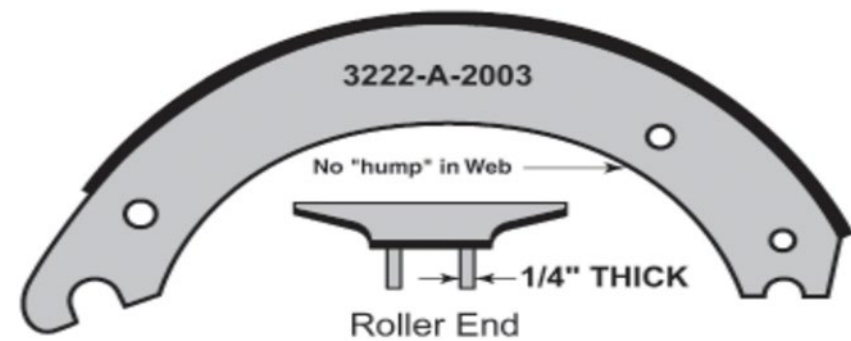
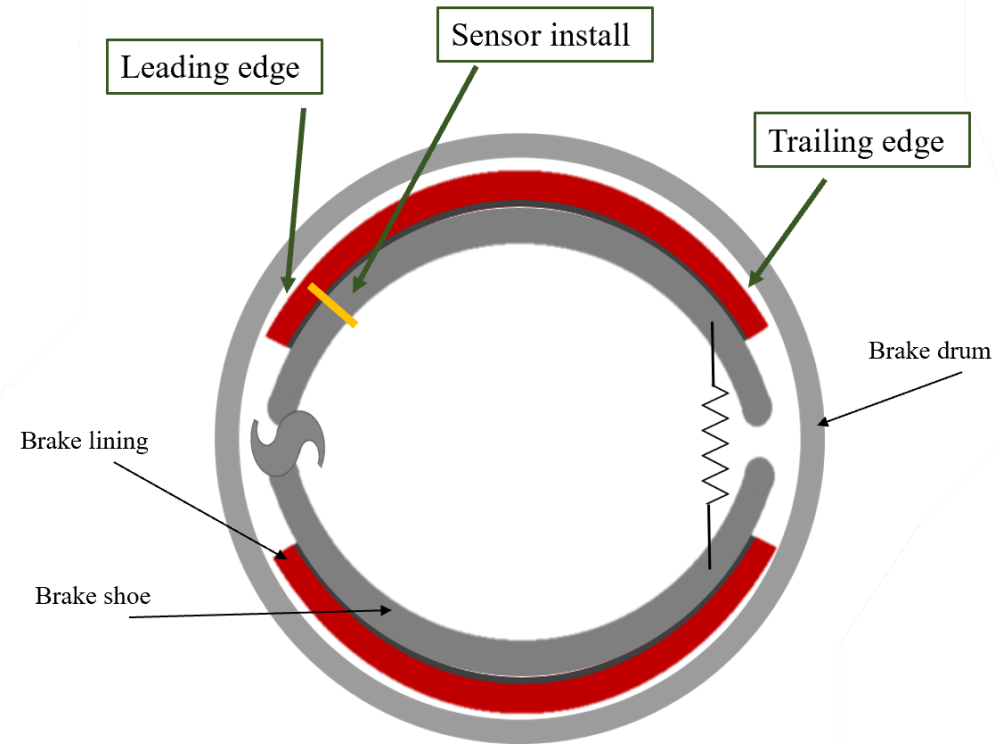
Long Distance Highway Route



## Test Vehicle

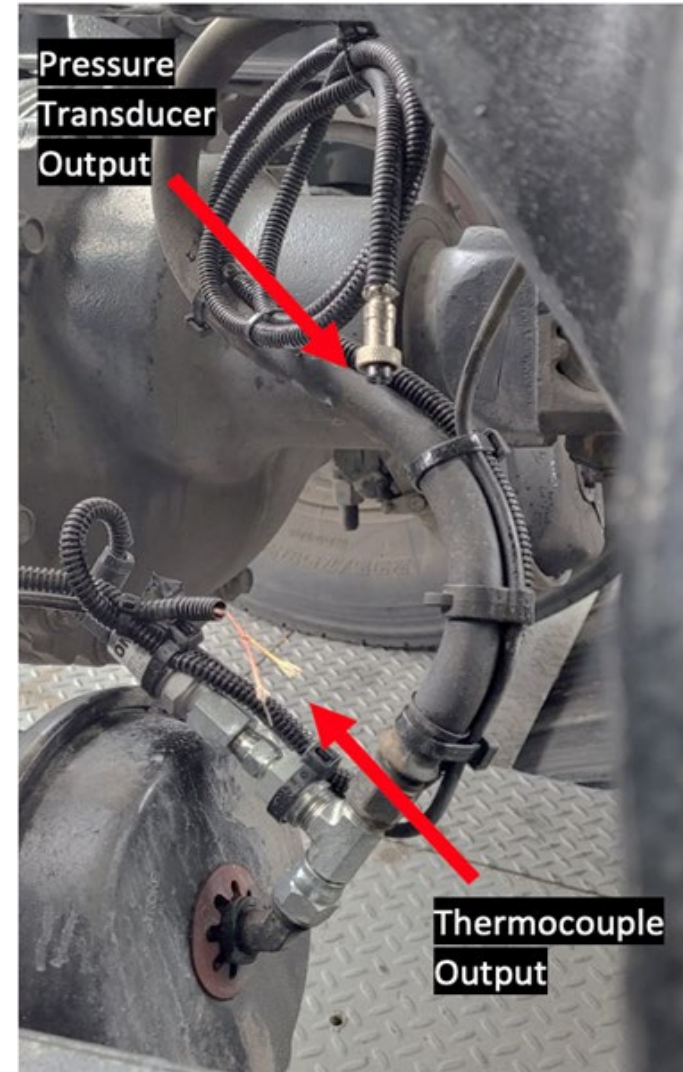
- HDV: Freightliner Cascadia 2015
  - 12.8 L Detroit Diesel engine with air brake system
  - Curb weight: 15,892 lb.
  - Total vehicle weight (tractor + trailer): 65,000 lb.

# Temperature Installation



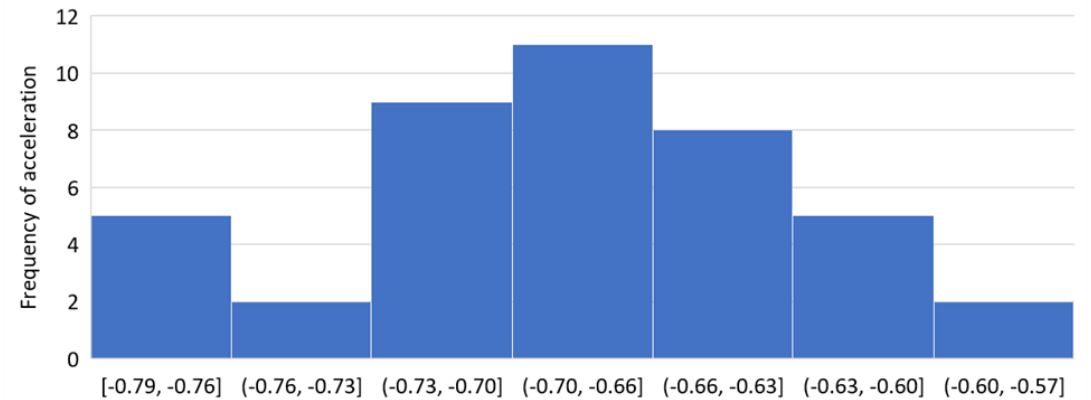
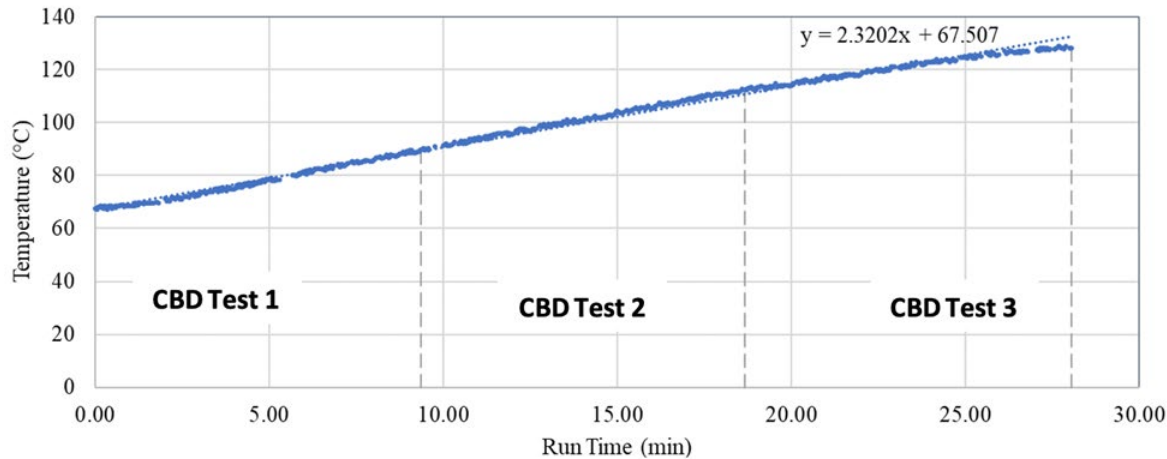
# Data Collection

- K-type thermocouple
  - 1/8 copper tube encasing
  - 2 mm below brake pad material
- Pressure transducer
  - Brake fluid line to the rear right brake canister.
- Brake datalogger
  - 1 Hz data sampling
- OBD2 HEM logger
  - GPS, vehicle speed, altitude
  - 1 Hz data sampling
- Ambient conditions
  - local weather stations managed by the California Irrigation Management Information System (CIMIS)

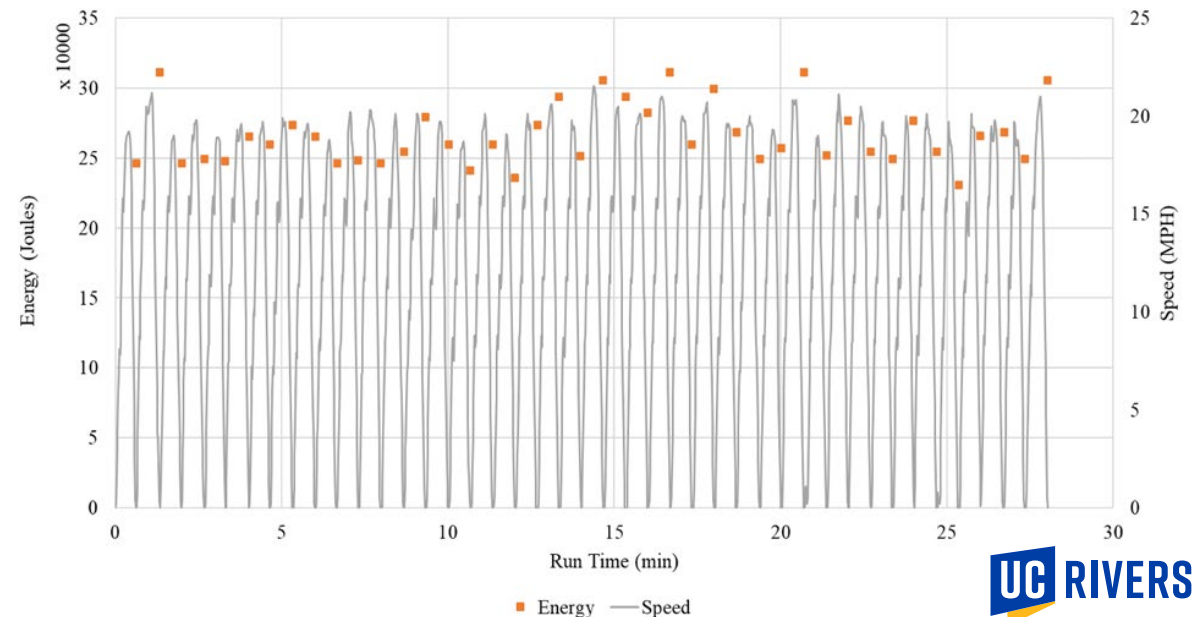


**Brake datalogger**

# CBD Cycle: Brake Temperature, Acceleration & Kinetic Energy Lost



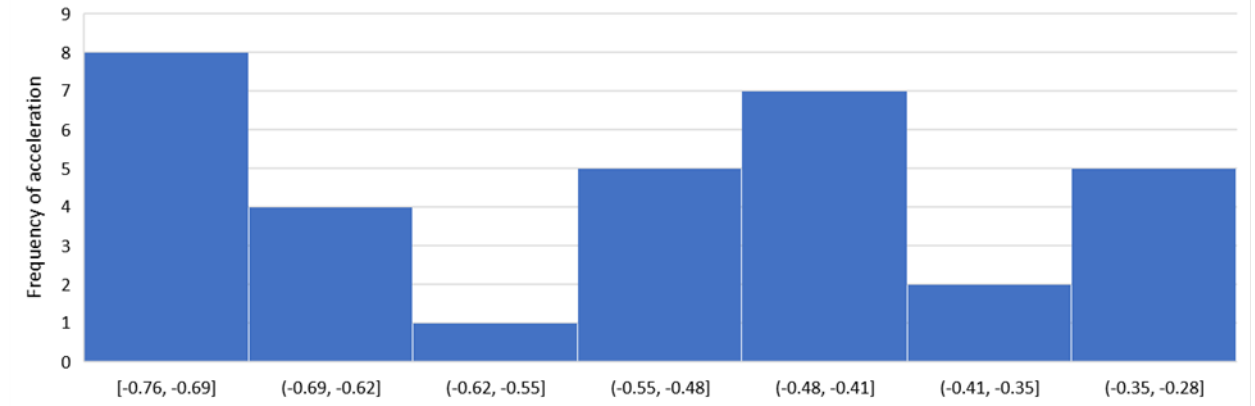
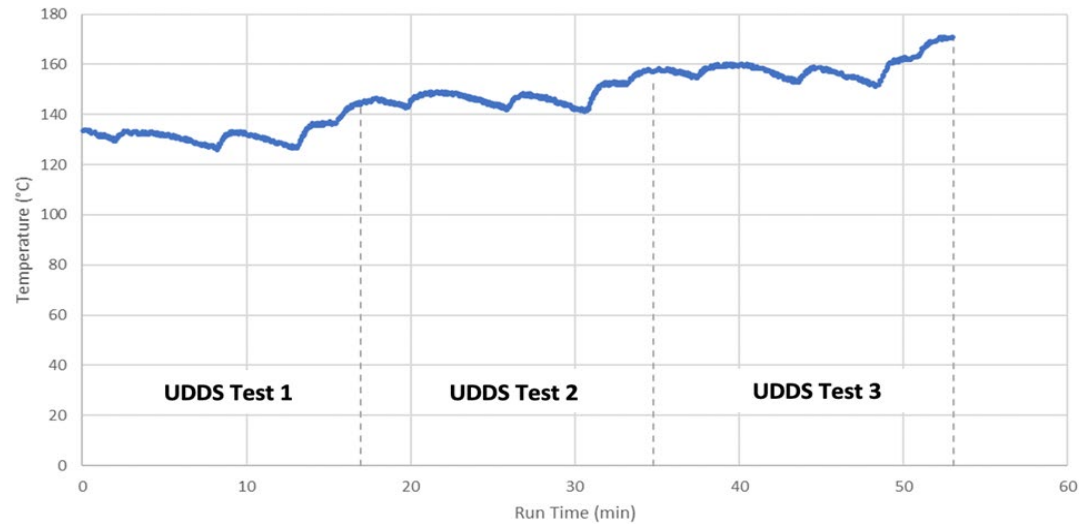
- Negative acceleration values were approximately linear.
- the brake pressure varied from 20 psi to about 30 psi with one spike up to 38 psi
- Average kinetic energy lost compared to temperature slope within each CBD cycle, divided by number of brakes:
  - $2.4E-5$  °C/J,  $2.3E-5$  °C/J, and  $2.3E-5$  °C/J



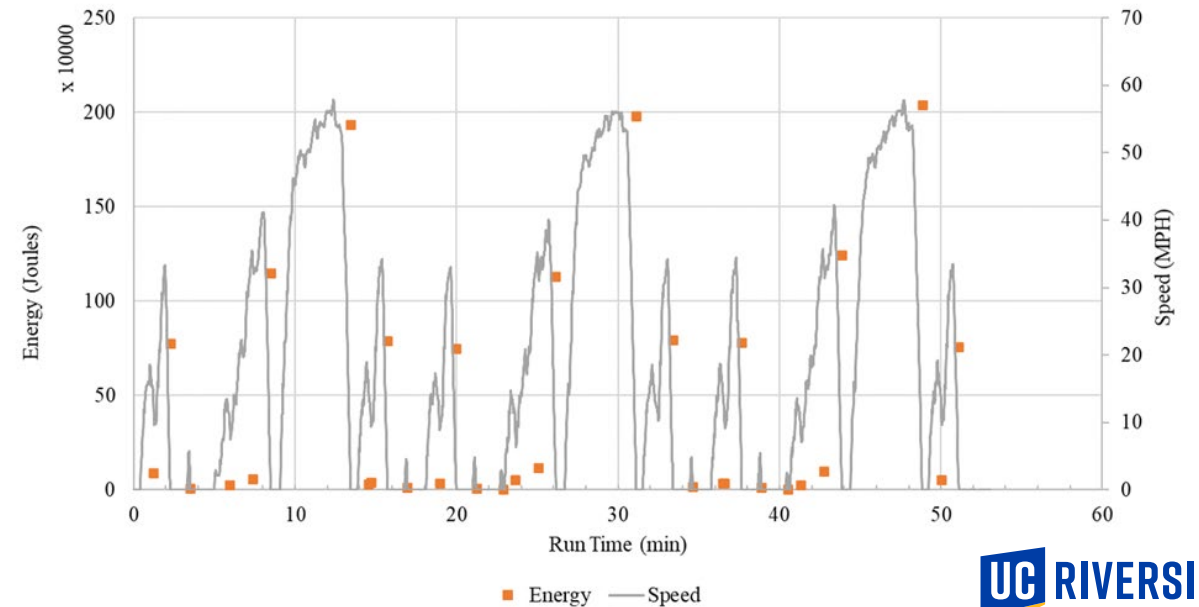
Values of kinetic energy lost (J) were multiplied by a factor of -1 to display positive numbers during deceleration events



# UDDS Cycle: Brake Temperature, Acceleration & Kinetic Energy Lost

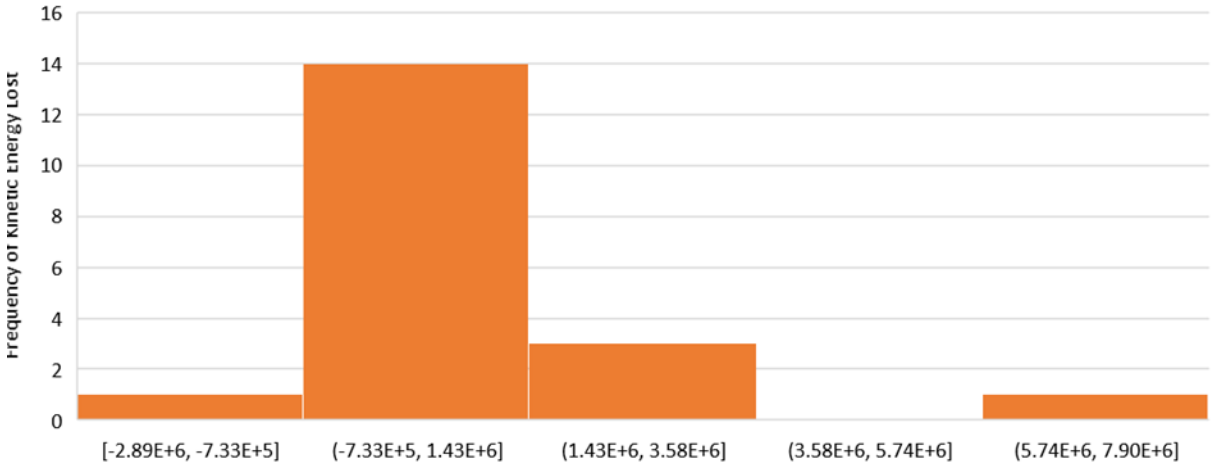
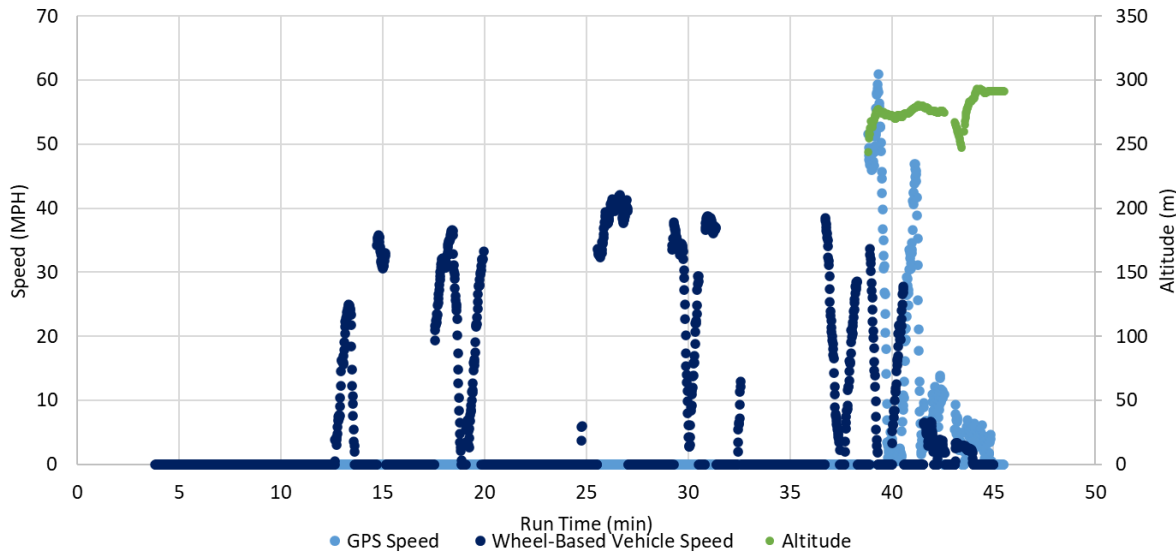


- 20-minute delay between the CBD and UDDS tests
- brake pressure varied from 10 psi to about 30 psi with one spike up to 45 psi
- Average kinetic energy lost for each cycle:
  - $2.6E5$  J,  $2.7E5$  J, and  $2.6E5$  J

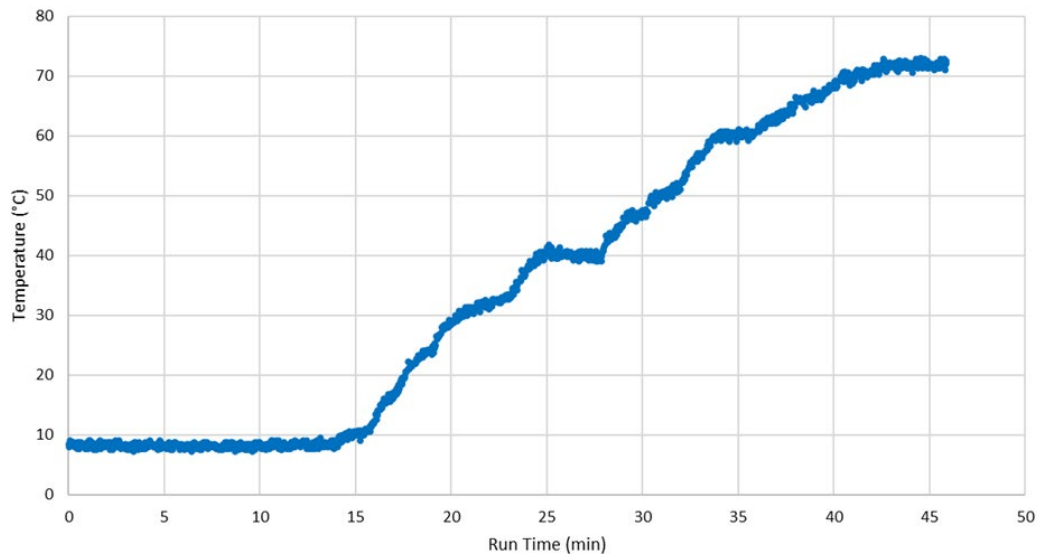


Values of kinetic energy lost (J) were multiplied by a factor of -1 to display positive numbers during deceleration events

# On-Road Test: Riverside City

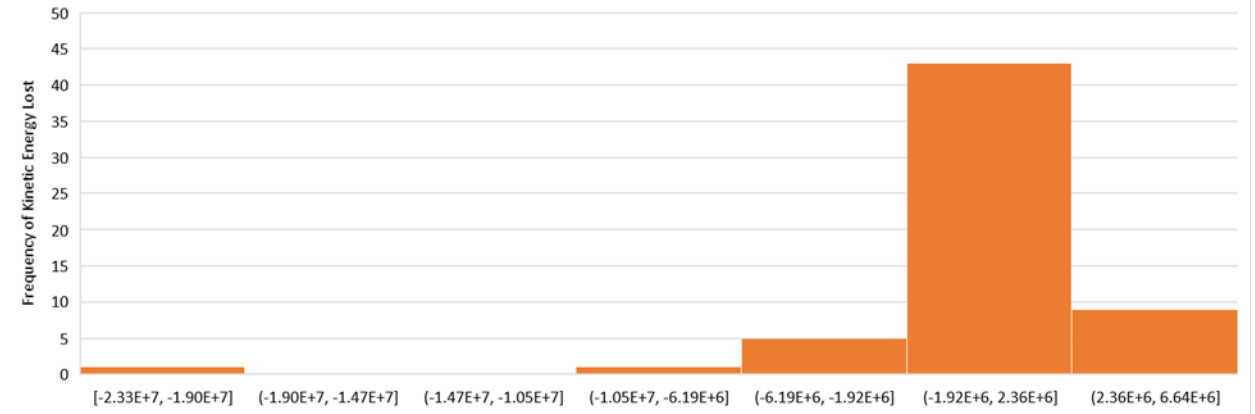
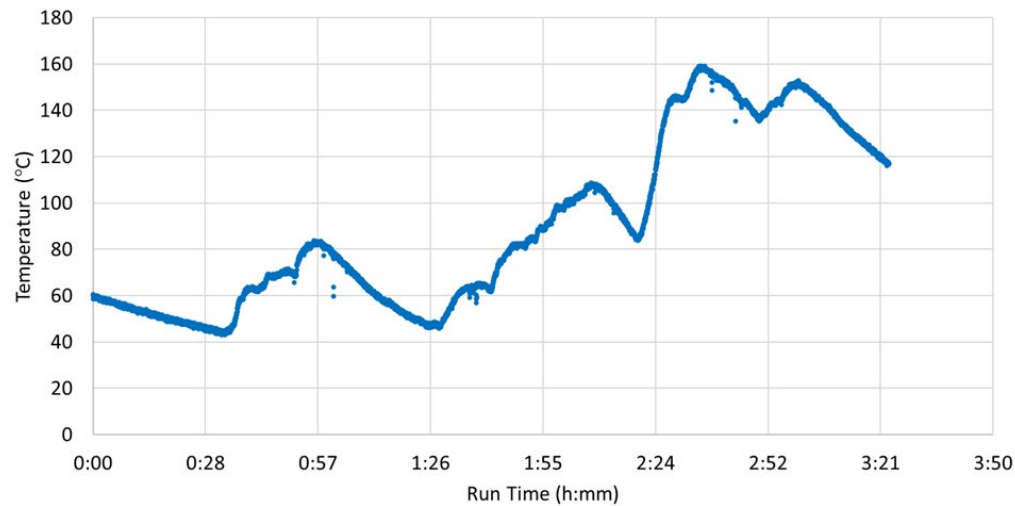
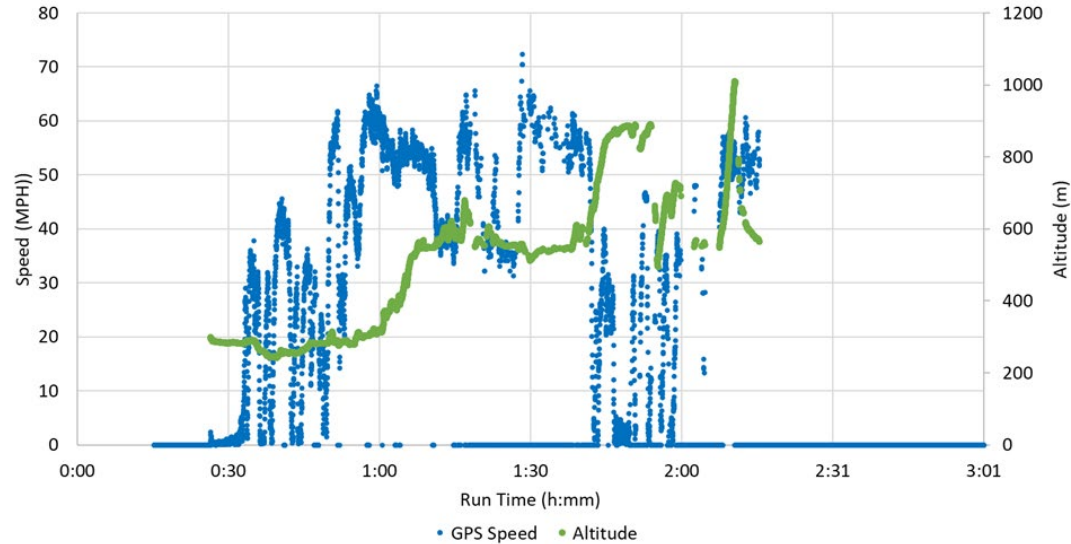


Values of kinetic energy lost (J) were multiplied by a factor of -1 to display positive numbers during deceleration events



- Average acceleration ranged from  $-4.43E-1$  to  $-2.56E-2$   $m/s^2$
- The pressure ranged from 10 psi to 20 psi with a few spikes as high as 33 psi.
- Braking energy lost suggests a higher frequency in the  $-7.33E5$  to  $1.43E6$  Joule bin compared to the chassis testing.

# On-Road Test: Highway

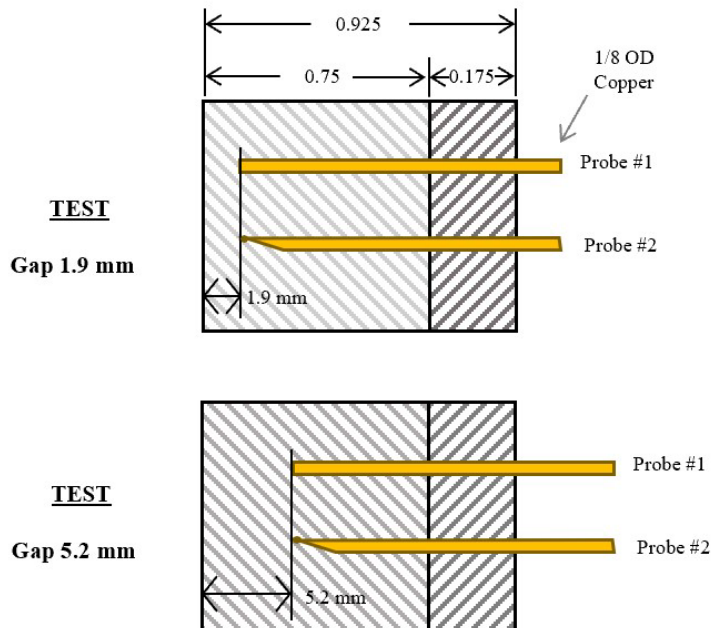
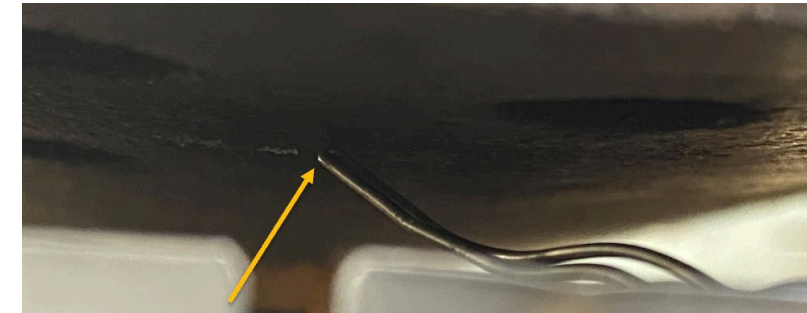


Values of kinetic energy lost (J) were multiplied by a factor of -1 to display positive numbers during deceleration events

- Brake pressure was around 20 psi with several spikes over 30 psi and one up to 39 psi.
- Kinetic energy lost contains negative values attributed to road elevation and travelling downhill.
- KE 2-3 times larger than chassis tests.

# Bench Top Laboratory Testing

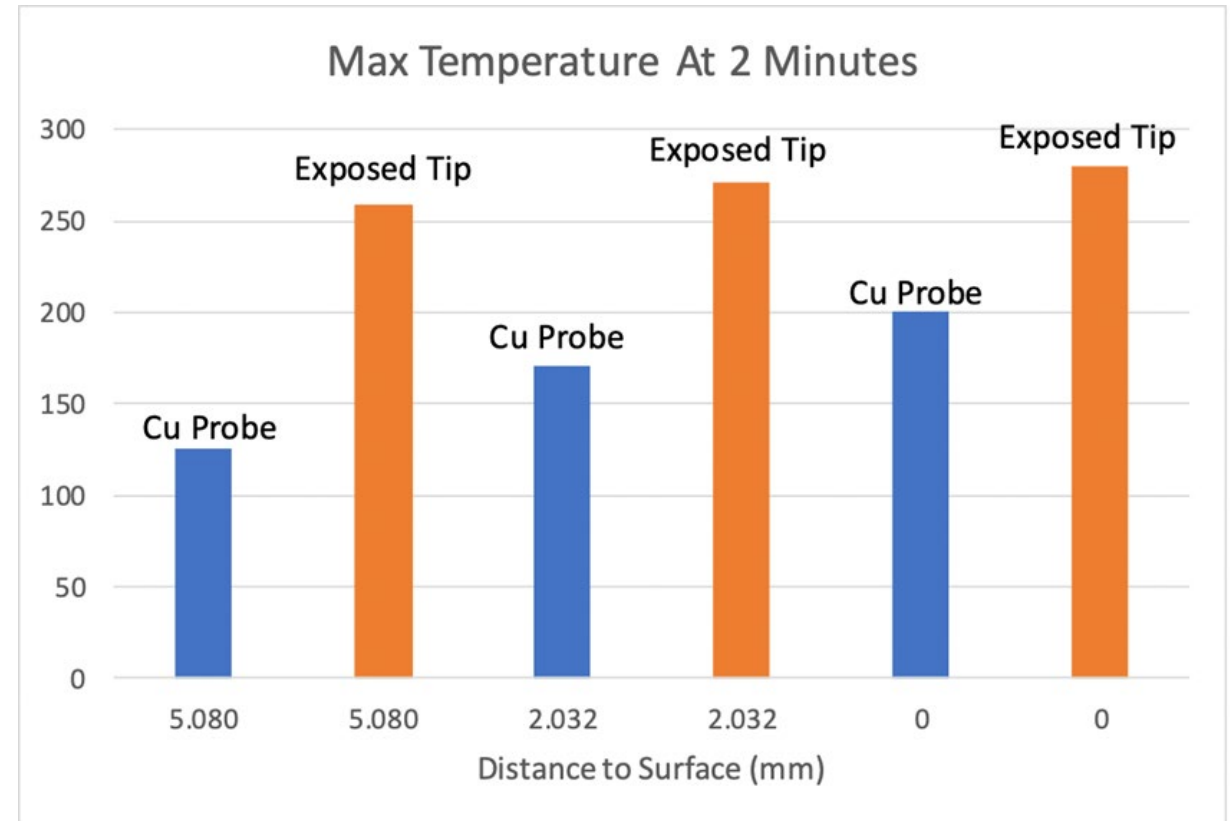
- A lab experiment was setup to evaluate the temperature probe in the “as-found” condition.
- Butane camping stove was setup to produce a 3” diameter blue flame ~1” from the surface.
- Data was logged with a CR10x data logger.



Probe tips: brake test probe (bottom) used in the study and exposed tip (top).

# Bench Top Laboratory Testing Cont...

- Overview of the maximum temperature reached after 2 minutes.
- Difference between the exposed tip and Cu probe was about 100 °C to 150 °C.
- The 0 mm was estimated from the 5 and 2 mm depths tests and was not measured.
- Suggest braking temperatures may be low by around 100 C.



# Key Findings

- The brake activity widely varied between laboratory cycles and on-road test.
- It should be noted brake activity from the same vehicle can vary as a function of hauling load.
- Brake pressures ranged from 20 psi typically up to a maximum of 45 psi.
- Brake temperatures ranged from 60C to 160C where it is possible the maximum temperature could be over 260C if the correct temperature probe were utilized.

# Future Work

- Utilizing an exposed tip thermocouple to measure brake pad temperature at the targeted depth of 2 mm.
- Simultaneous measure the brake particle emissions along with brake activity to find relationship between brake activity and brake particle emissions.
- Measure brake activity for vehicles with different vocations such as sweeper vehicle, buses, trucks as well as other applications.

# Acknowledgements

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**Thank You**