CALIFORNIA
AIR RESOURCES BOARD

Mobile Hydraulic Dynamometer (MoHyD)

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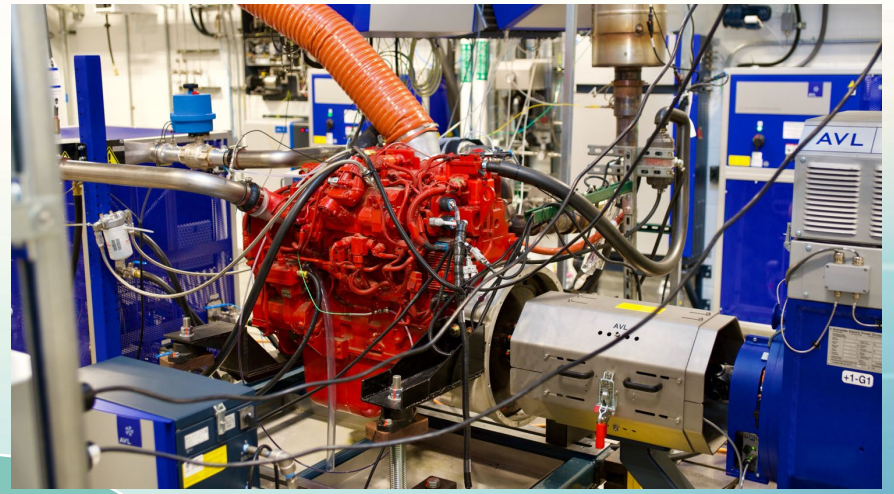
Agenda

- MoHyD
  - Background
  - What is MoHyD?
  - General Specifications
- Testing with MoHyD
  - Equipment Tested
  - Test Data
- Current & Future Plans
  - Alternative Test Method
  - Next Steps

MoHyD

Background

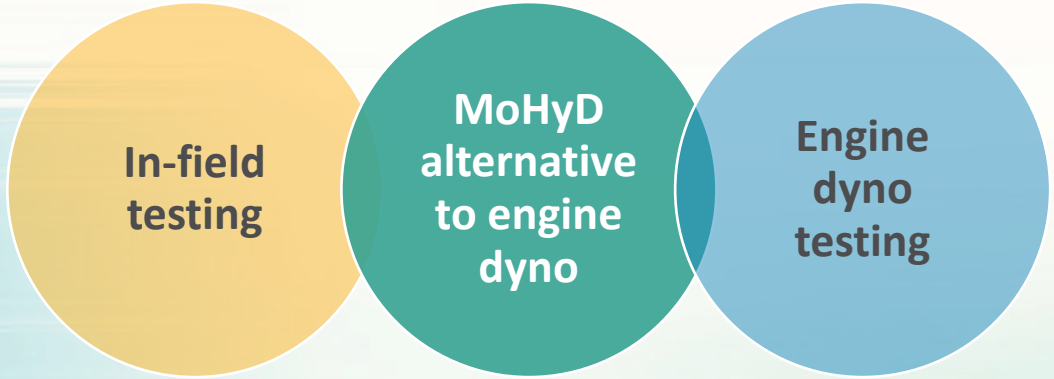
Available testing options for in-use emission measurement

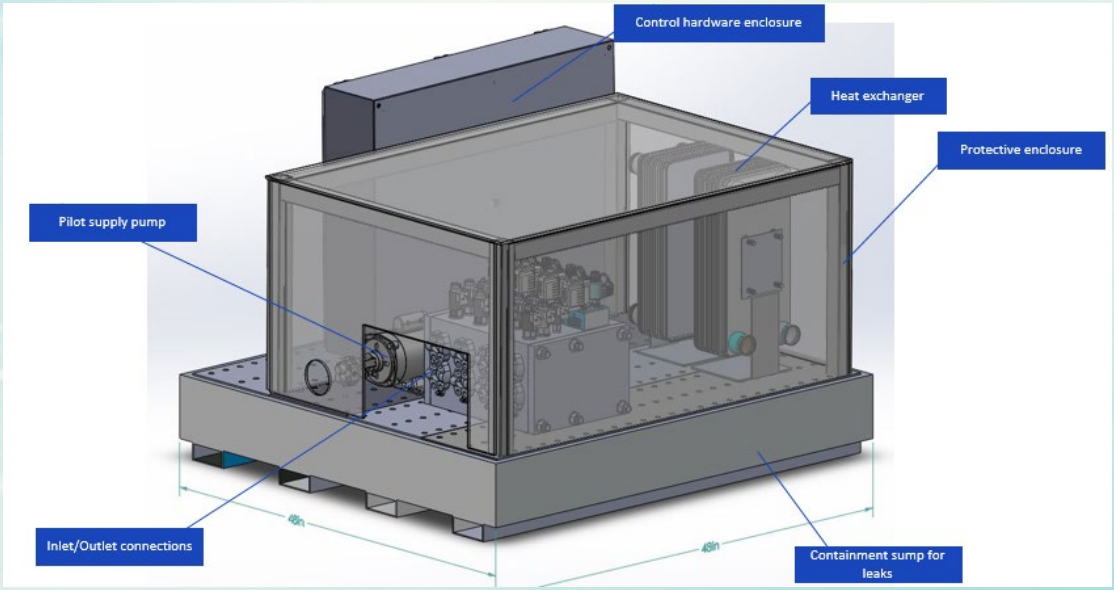


In-field testing - PEMS

Engine dyno testing – lab analyzers

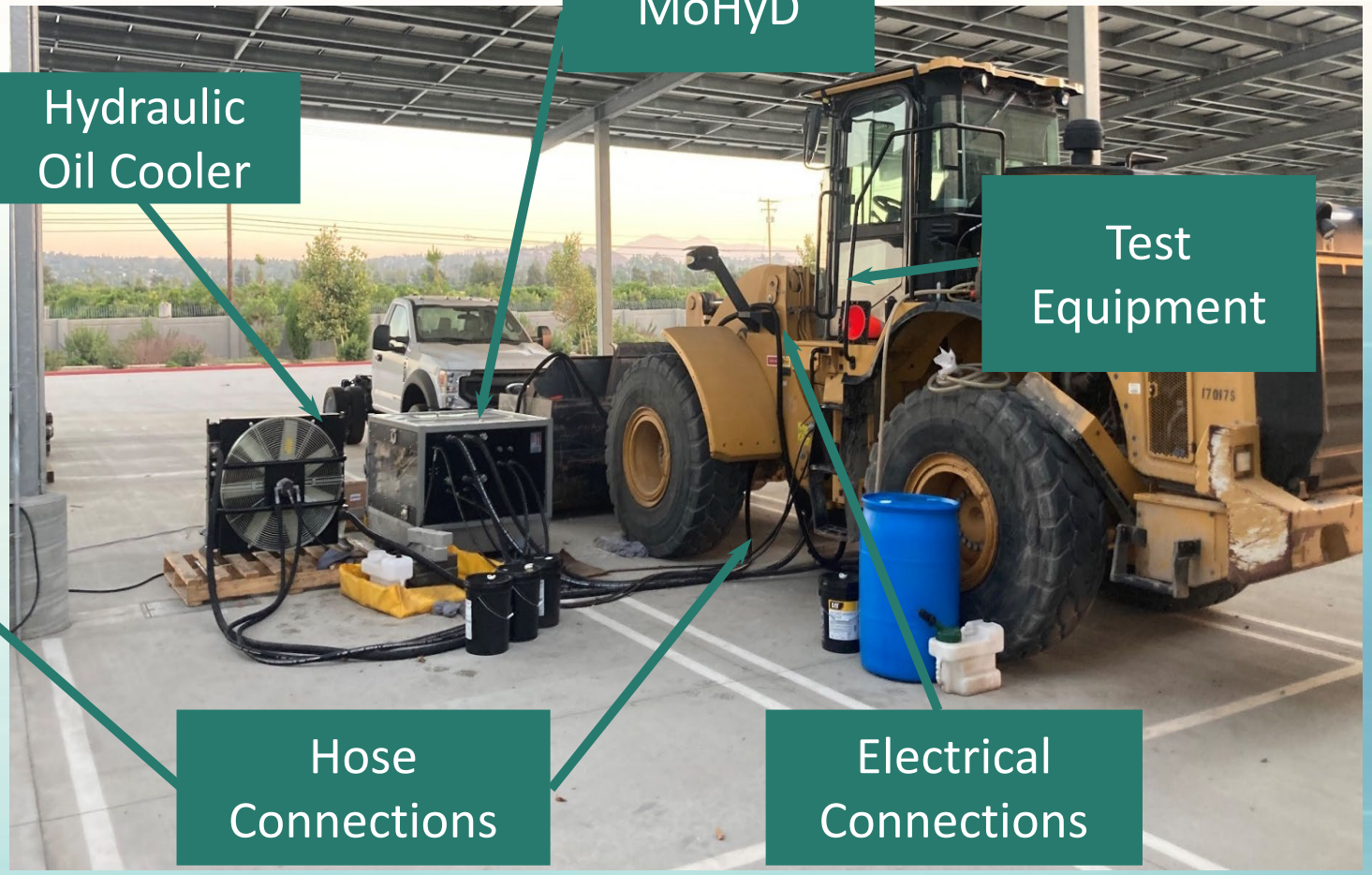
What is MoHyD?





- MoHyD is a standalone instrument that connects to the hydraulic system of the off-road equipment
- Capable of loading and operating the engines without removing the engines from the equipment
- Can mimic the operation of an engine dynamometer over various cycles: Non-Road Transit Cycles (NRTC) and Ramped Modal Cycles (RMC)

Typical MoHyD Set Up



General Specifications

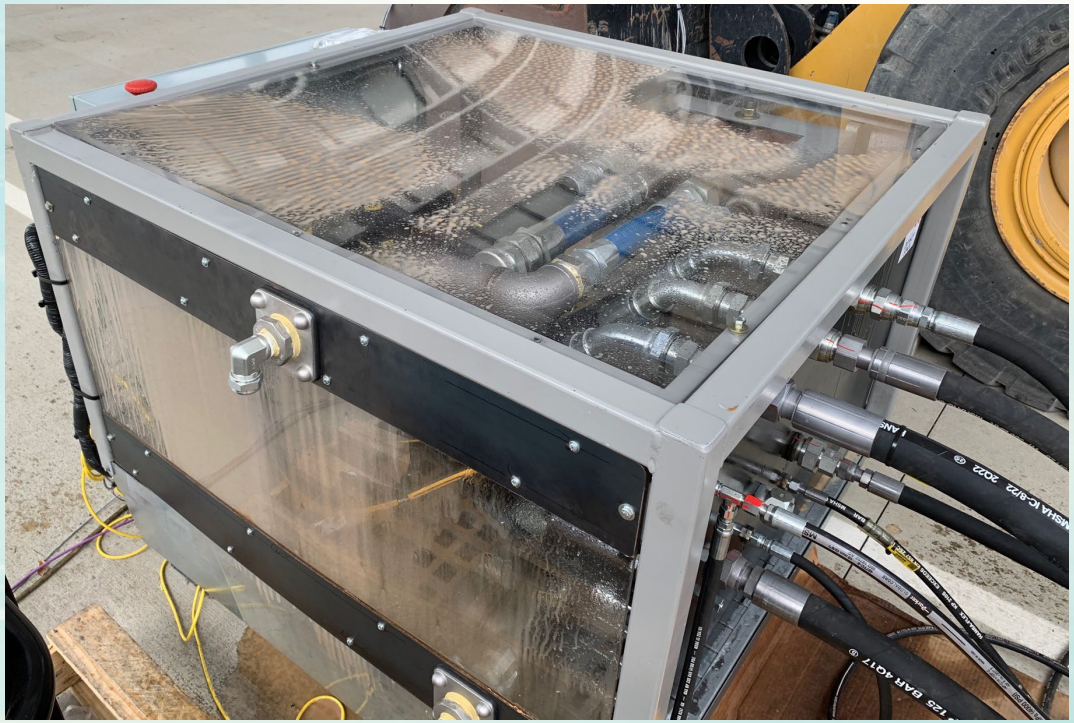
- Closed/open looped valve system
- Electric control system
- Additional hydraulic fluid cooler and hydraulic cooling fans
- Electronic computer

Overall MoHyD Specifications		
Parameter	**Value**	**Notes**
Maximum Power	298 kW (400 hp)	
Maximum Flow	1600 lpm (424 gpm)	Limited by max permissible flow meter
Maximum Fluid Temperature	70 ˚C (158 ˚F)	Limited by temperature rating of flow meter
Maximum Pressure	350 bar (5,089 psi)	
Maximum Ambient Temperature	50 ˚C (122 ˚F)	Limited by Compact RIO controller
System Cleanliness	ISO 4406 class 20/18/15	

Electrical Interface to the Test Unit

- Connections to test machine
  - Pedal position control
    - CAN, PWM, Analog
  - CAN bus (OBD port & proprietary CAN buses)
  - PWM outputs for controlling electronic pumps
  - Parking brake solenoid valves as needed

Safety Features



- Enclosed system with Plexiglass
- 40 gallons containment pan
- Pressure relief valves @manifold
- Pressure and temperature sensors @manifold
- Secondary containment at connecting areas
- Three E-stop feature
- Remote Start-Stop
- LOTO (Log Out Tag Out)

Advantages of MoHyD

- Simulate RMC, NRTC, low and high load operation, or any other duty cycles from the field
- Perform PEMS testing at any location
- Dirt-free conditions
- No seasonal limitation for testing equipment
- Cost effective

Testing with MoHyD

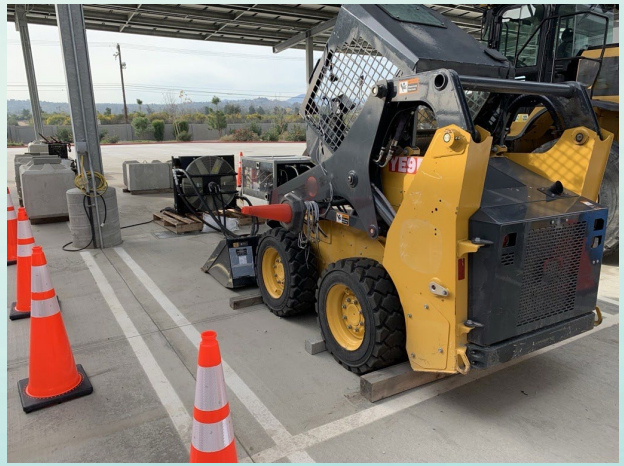
Equipment Tested

Skid Steer 1

- 2022 MY
- 55kW
- 3L
- ~100 hours

Skid Steer 2

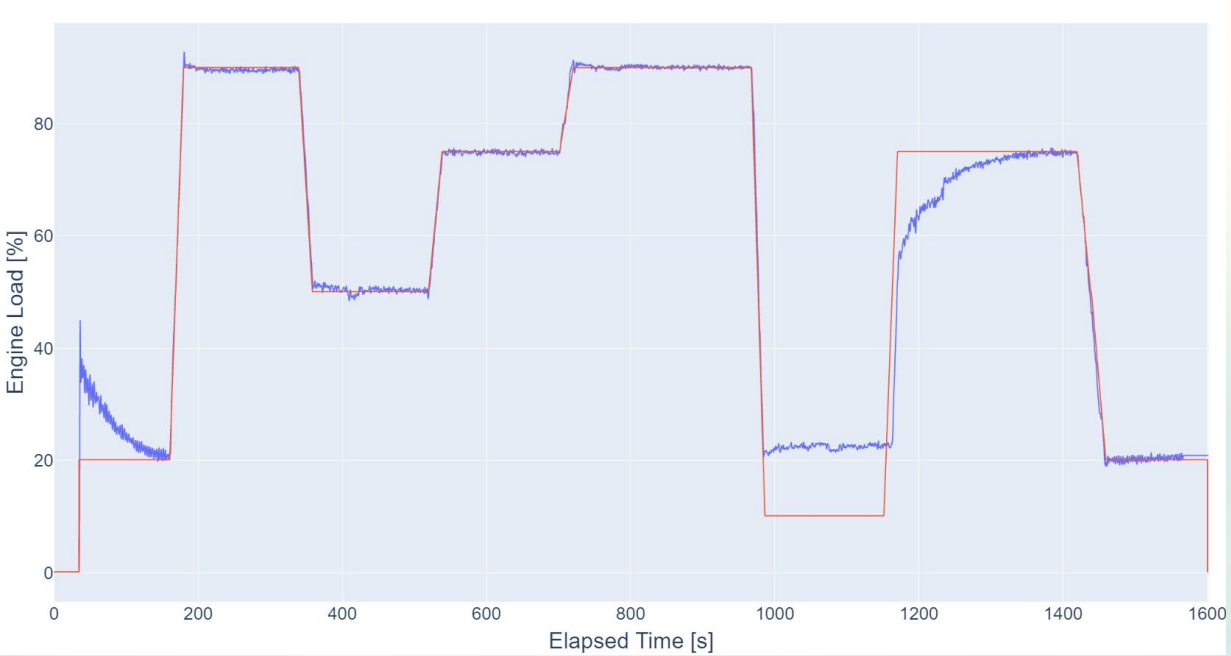
- 2022 MY
- 37 kW
- 2L
- ~350 hours



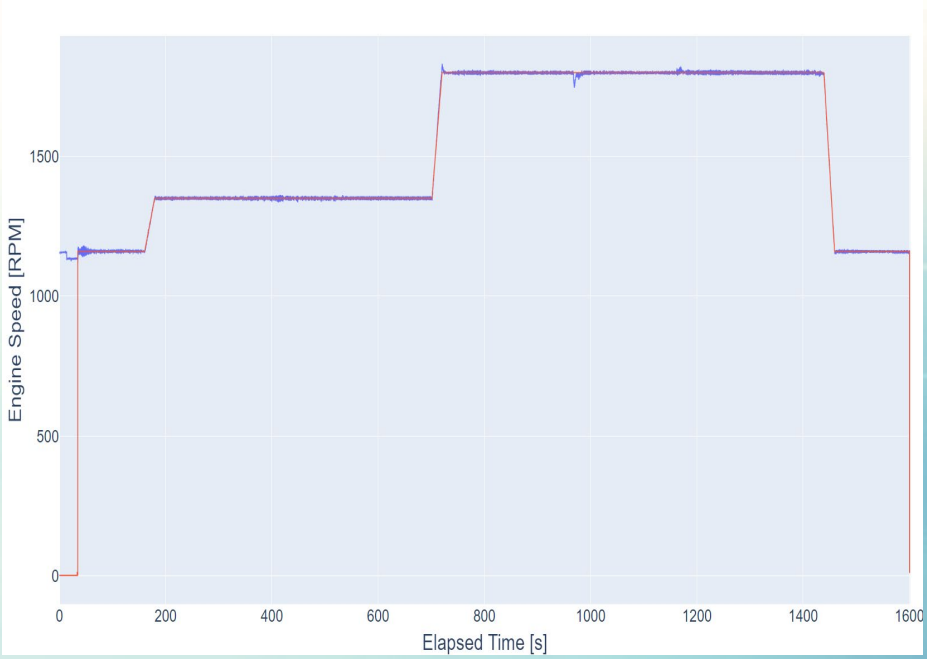
Wheel Loader

- 2017 MY
- 201 kW
- 7L
- ~3000 hours

Skid Steer 1 (RMC)



Load

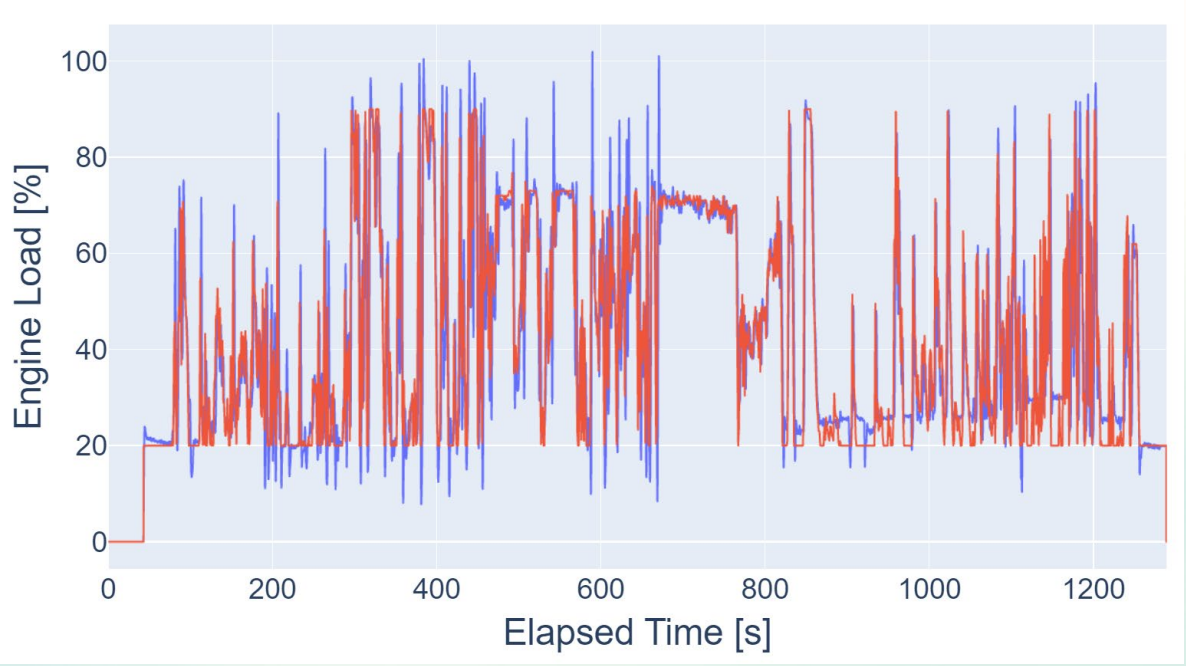


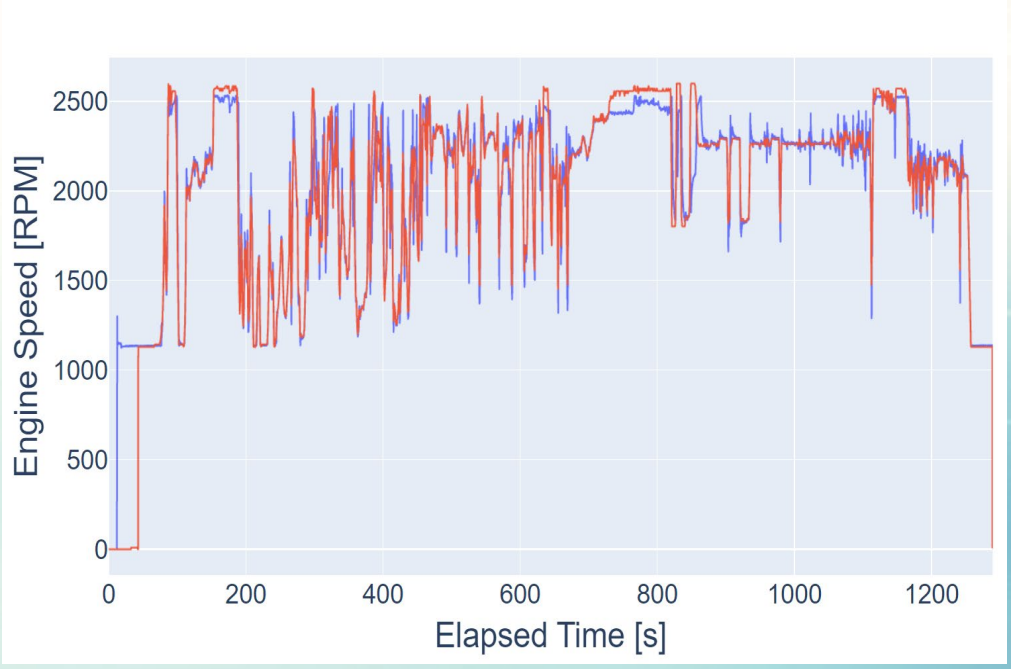
Speed

Set Point
Actual Value

CARB

Skid Steer 1 (NRTC)





Set Point
Actual Value

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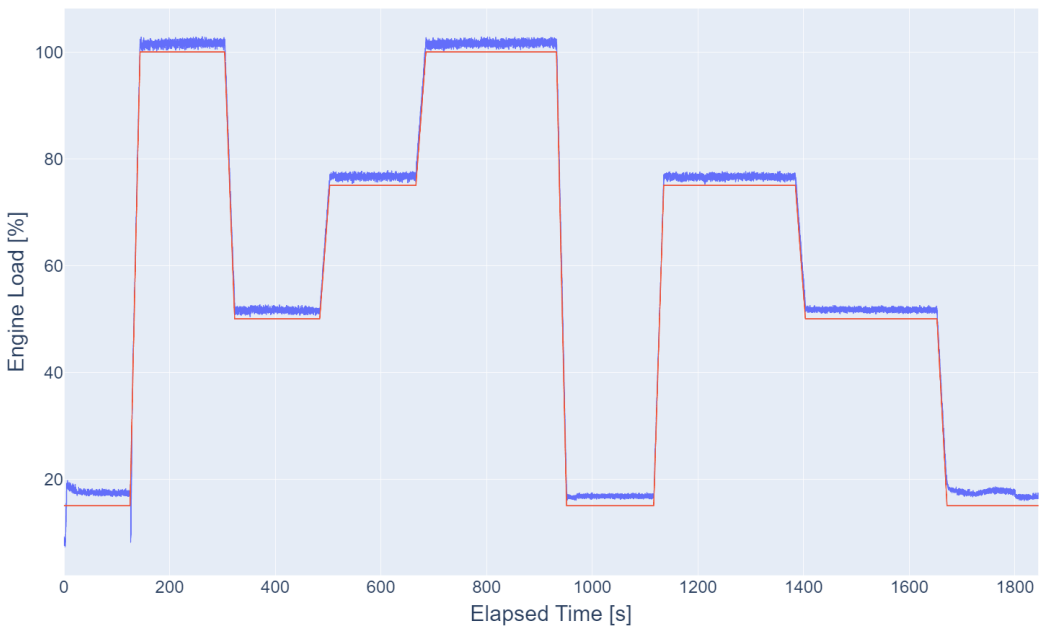
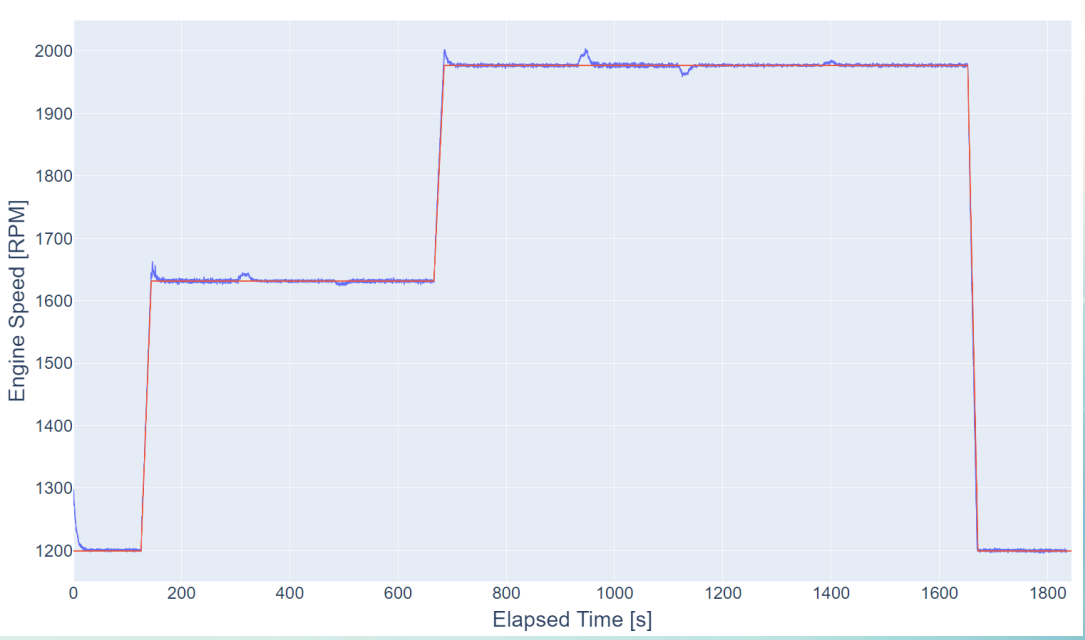
Skid Steer 2 (RMC)



Slope: **0.998 (>0.83)**
R^2: **0.997 (>0.85)**

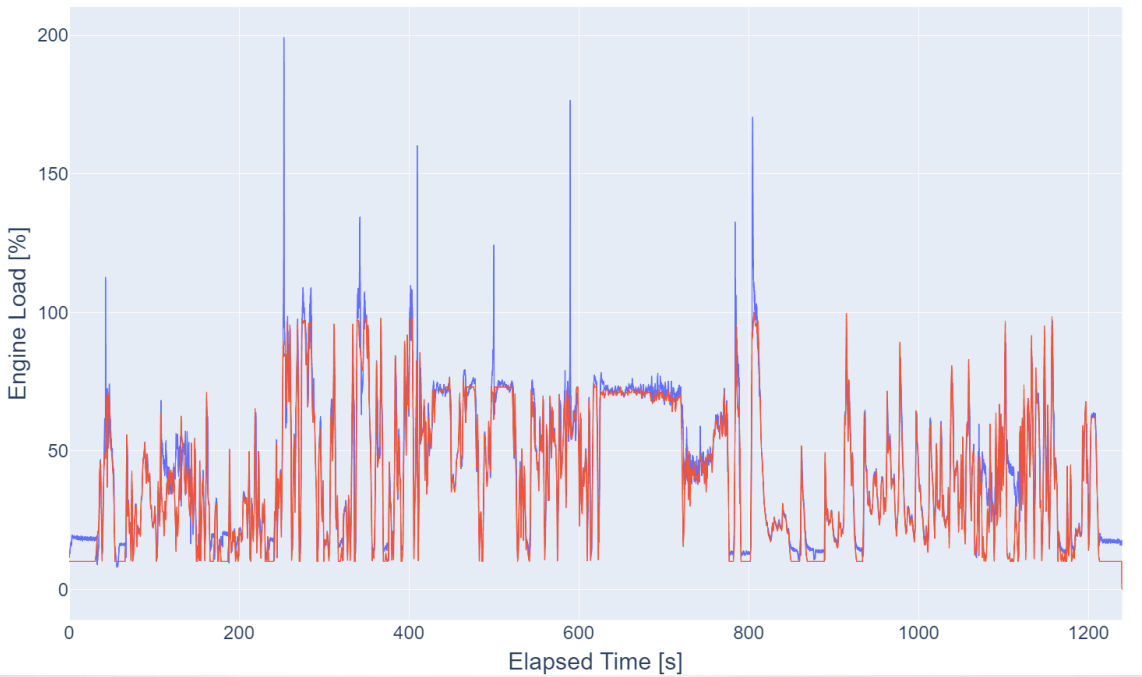


Slope: **0.999 (>0.95)**
R^2: **0.999 (>0.97)**

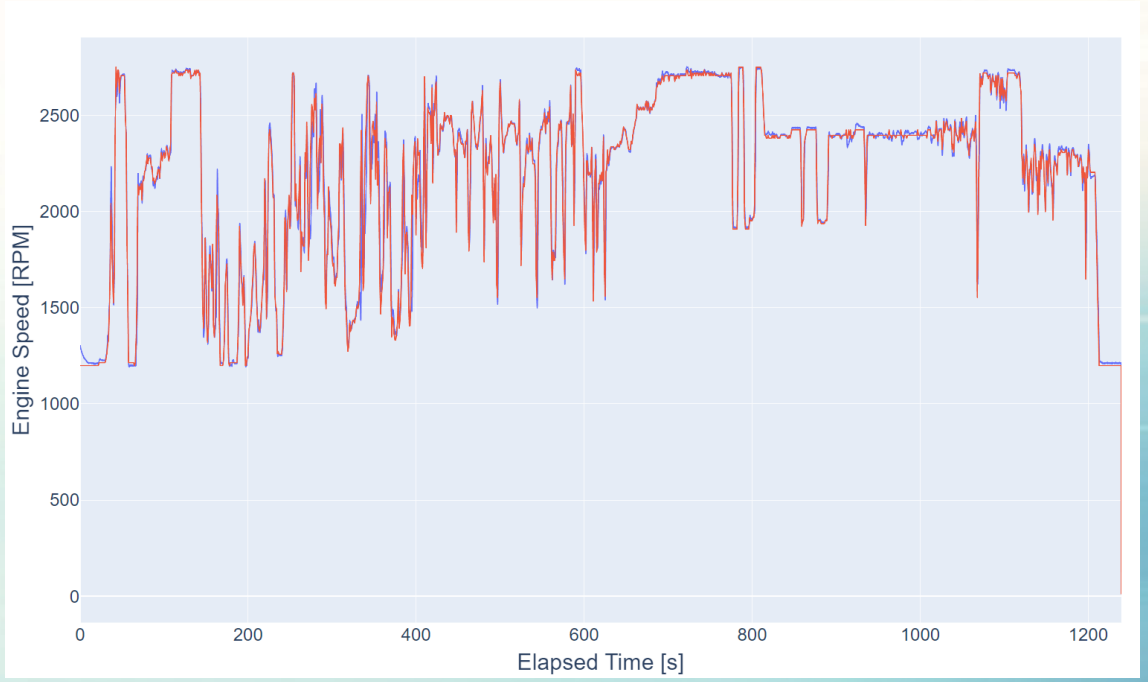
Set Point
Actual Value

CARB

Skid Steer 2 (NRTC)



Slope: **0.955 (>0.83)**
R^2: **0.970 (>0.85)**



Slope: **0.994 (>0.95)**
R^2: **0.989 (>0.97)**

Set Point
Actual Value

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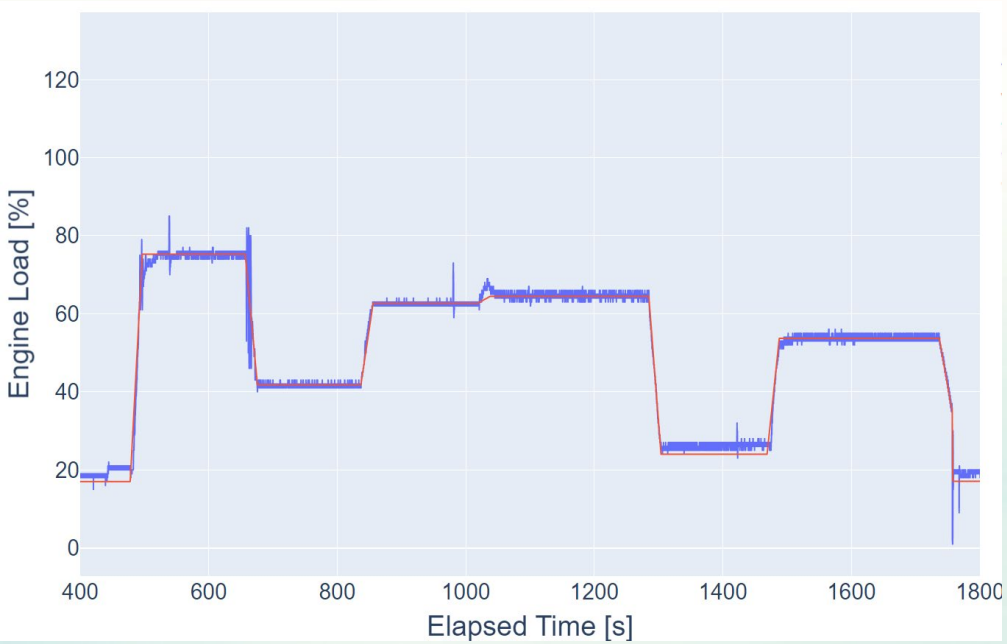
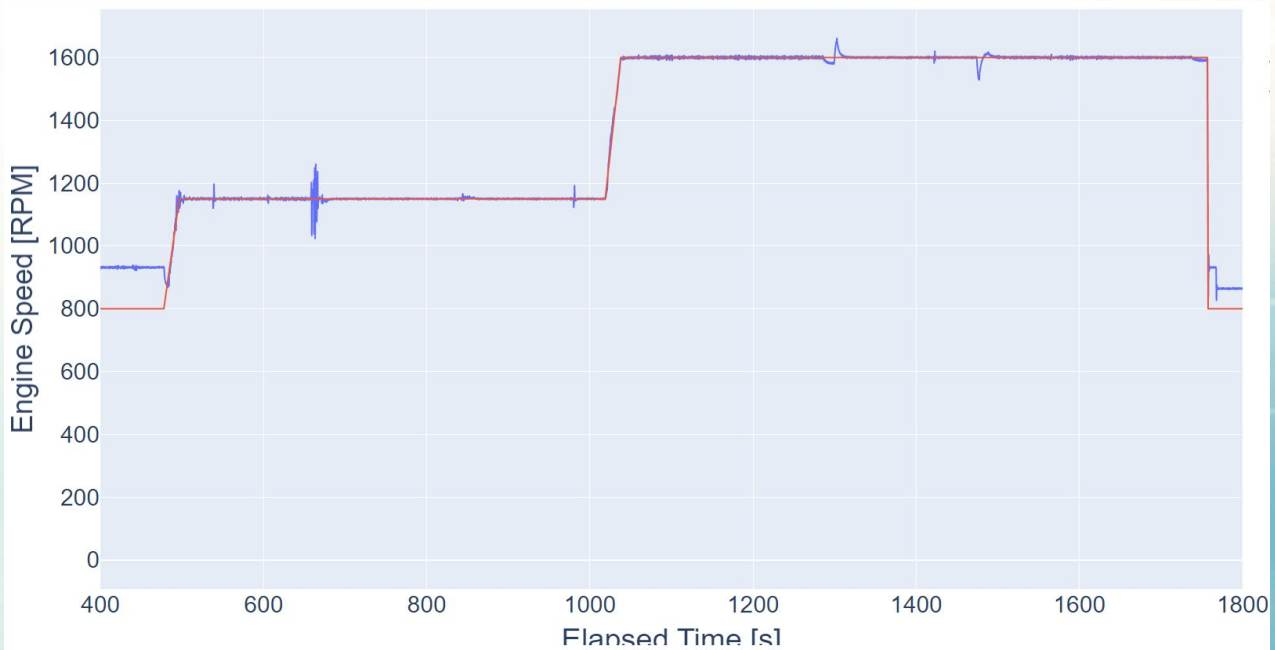
Wheel Loader (RMC)



Slope: **0.9 (>0.83)**
R^2: **0.97 (>0.85)**

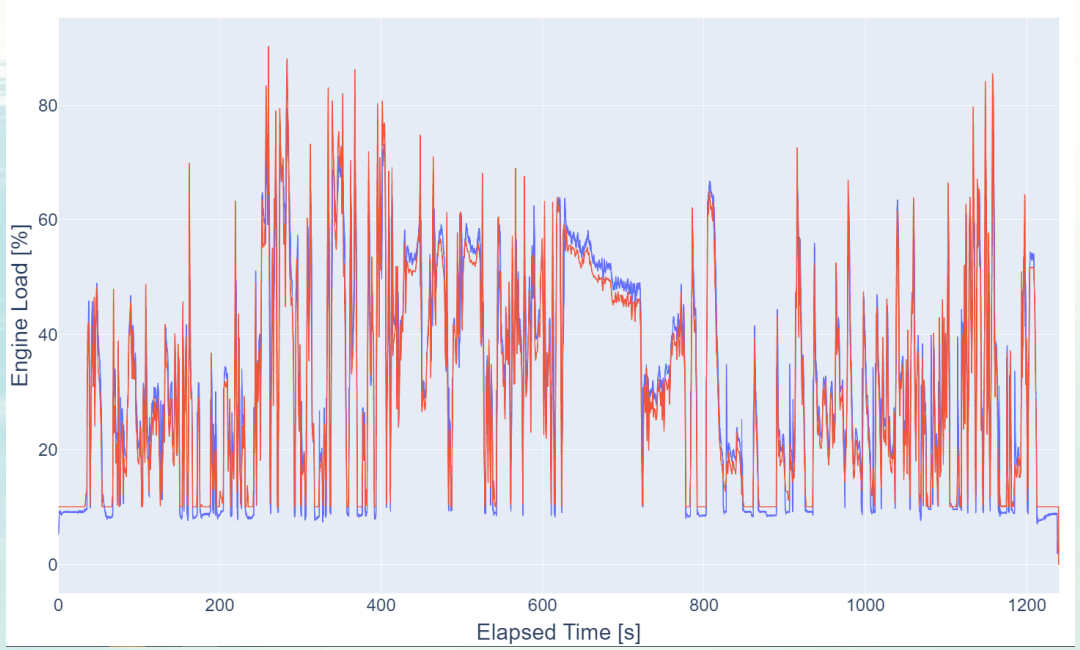


Slope: **0.96 (>0.95)**
R^2: **0.99 (>0.97)**

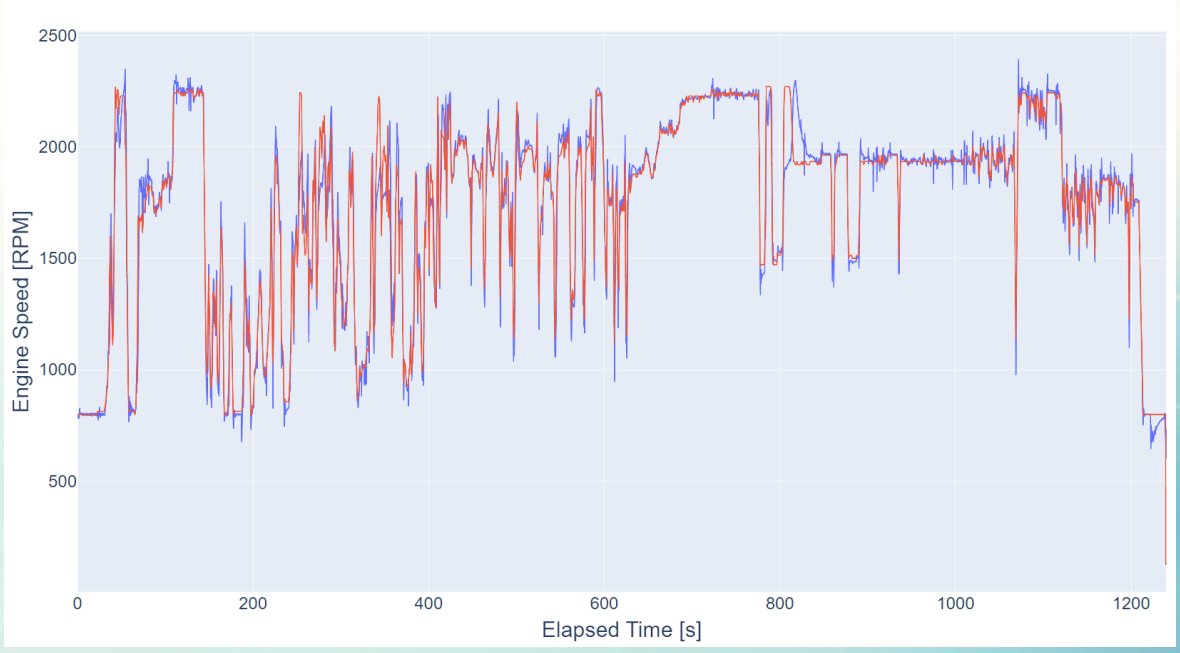
Set Point
Actual Value

CARB

Wheel Loader (NRTC)



Slope: **0.99 (>0.83)**
R^2: **0.92 (>0.85)**



Slope: **0.98 (>0.95)**
R^2: **0.96 (>0.97)**

Set Point
Actual Value

CARB

Current & Future Plans

Alternative Test Method

- Analyze data collected with the MoHyD over the certification test cycles on various equipment types to demonstrate the feasibility of MoHyD testing as an alternative 1065-compliant test method
- MoHyD needs to comply with 40 CFR 1065 regulation (e.g. 1065.514 cycle-validation criteria)
  - 1065.510 Engine mapping, speed and torque uses 1 hz data collection
  - 1065.514 & 530 Transient duty cycle and feedback speeds and torques uses 5 hz data collection

TABLE 2 OF § 1065.514—DEFAULT STATISTICAL CRITERIA FOR VALIDATING DUTY CYCLES

Parameter	Speed	Torque	Power
Slope, a_1	$0.950 \le a_1 \le 1.030$	$0.830 \le a_1 \le 1.030$	$0.830 \le a_1 \le 1.030$.
Absolute value of intercept, $\lvert a_0 \rvert$	≤ 10% of warm idle	≤ 2% of maximum mapped torque.	≤ 2% of maximum mapped power.
Standard error of estimate, *SEE*.	≤ 5% of maximum test speed	≤ 10% of maximum mapped torque.	≤ 10% of maximum mapped power.
Coefficient of determination, r^2	≥ 0.970	≥ 0.850	≥ 0.910.

Next Steps

Goal:

- Validate MoHyD as an alternative test method for the in-use compliance testing following 40 CFR 1065.12
  - Testing looks promising
  - Additional development & improvements needed to refine MoHyD operation
  - Collect data from six additional equipment for further proofing the capability of MoHyD
  - Continue in-field testing with MoHyD

Thank You

Acknowledgments

Southwest Research Institute

CARB's PEMS Section

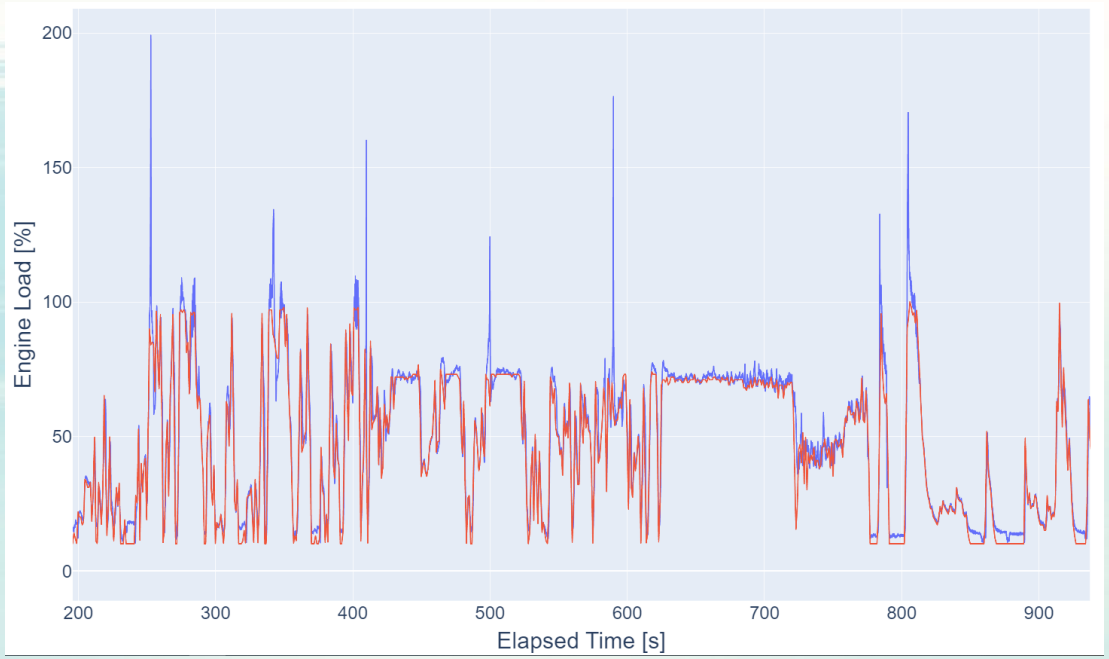
OEMs

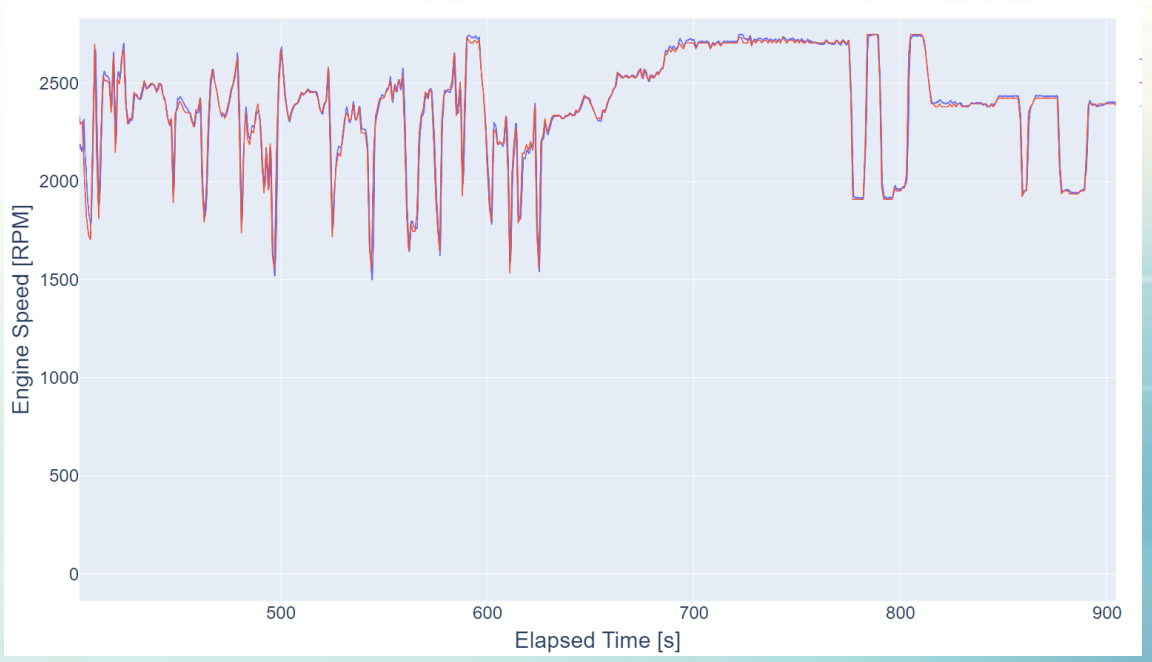
Back Up

Advantages of MoHyD

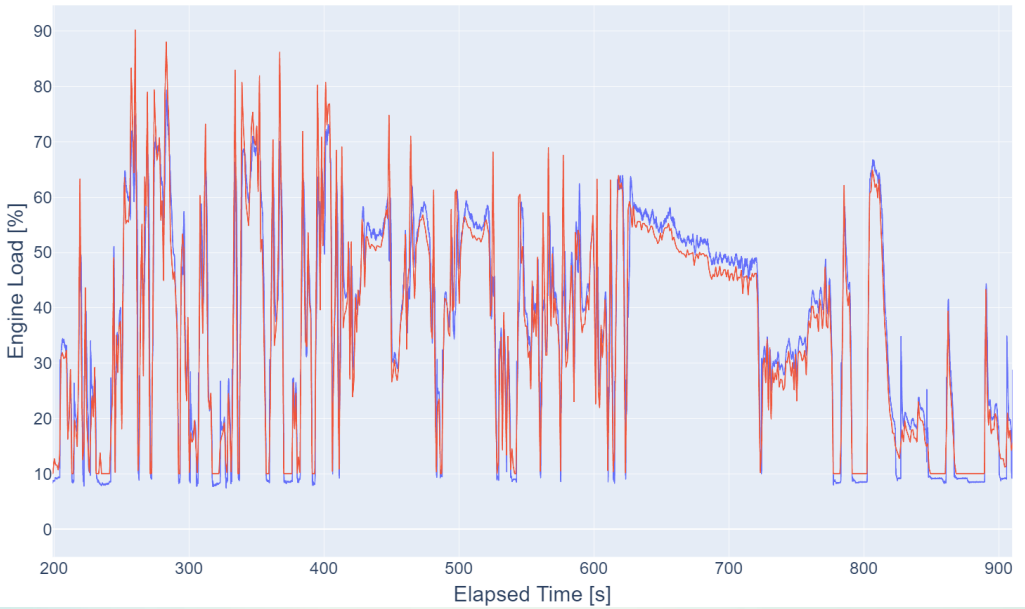
We Can	Details
Avoid removing engine from the equipment	• **Cost effective**: Save ~ $100,000 or more per equipment that would be needed to pull the engine out in order to conduct engine dyno testing (will need OEM's support for control) • **Improved work efficiency:** Compliance work can continue. The challenge with borrowed/rented equipment is that most probably we will not be allowed to remove the engine for testing
Simulate certification cycle	• **Simulate** RMC, NTE and NRTC cycle, low load, high load, or any other drive cycle without having to run the equipment in the field
Use it as a screening tool	• **Cost and time effective:** Once developed, this tool can be used as a screening tool to prioritize in-field in-use compliance testing
Test without OEM support	• Off-road equipment has no OBD regulation • For some – may **not need OEMs support** for ECU control

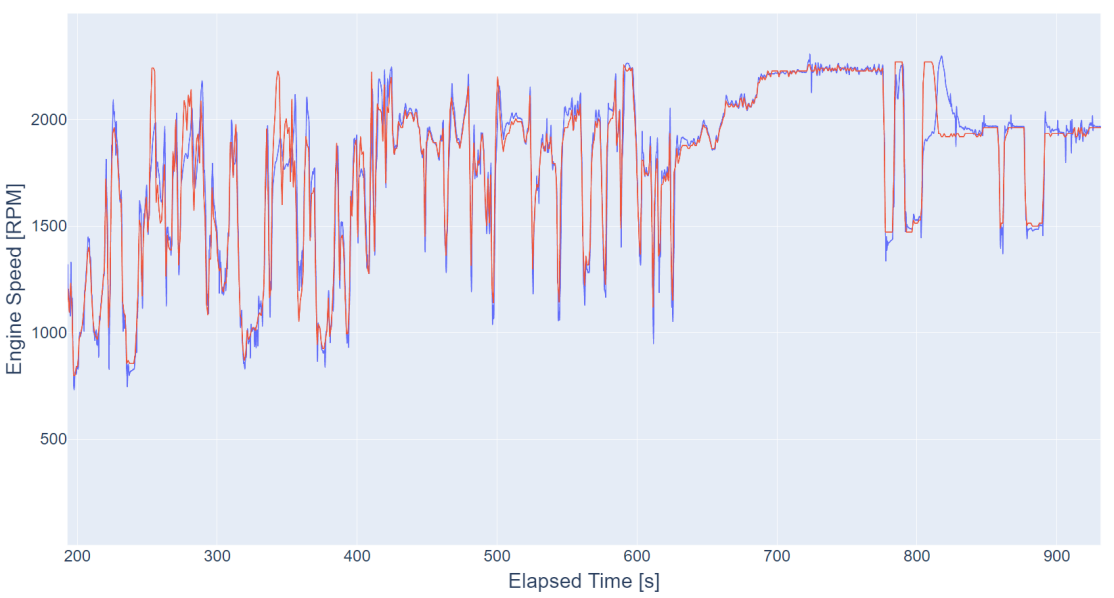
Skid Steer 2 (NRTC)





Wheel Loader (NRTC)





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