# Extending Exhaust Gas Recirculation Limits in CIDI Engines

**ORNL Investigators:**

**Johney Green (PI) and Robert Wagner**

**CRADA Collaborators:**

**Tony Davis, Lee Feldkamp, and John Hoard**

**(Ford Motor Company)**

**CRADA Supported by DOE-OAAT**

**Diesel Engine Emissions Reduction Workshop**

**Portsmouth, VA**

**August 5-9, 2001**

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

UT-BATTELLE

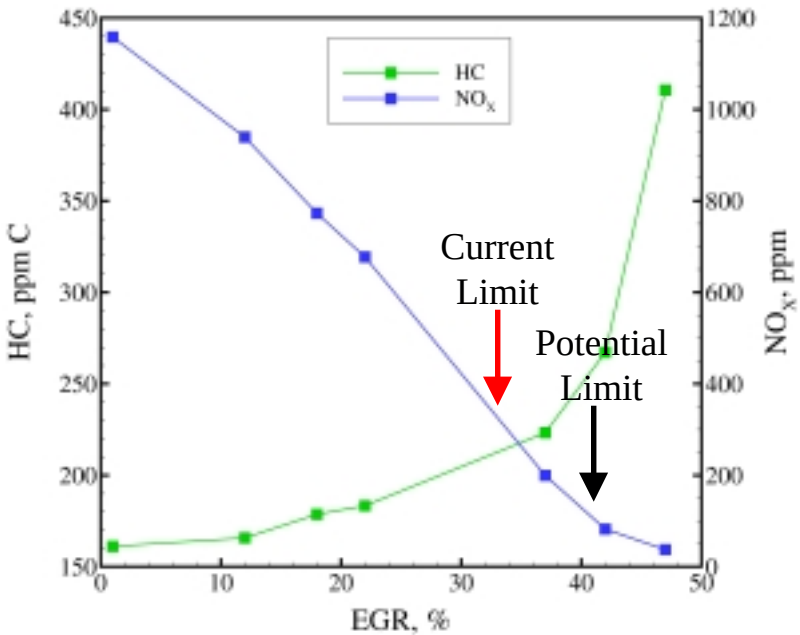
# ORNL is developing a combustion diagnostic to improve EGR utilization in CIDI engines

- **Objectives:**
  - **Reduce engine-out NOx emissions by approximately 50% with a minimal penalty for HC and PM emissions**
  - **Lower the performance requirements for post-combustion emission controls**
- **Challenges:**
  - **Actual EGR utilization is typically less than optimal because HC and PM emissions spike during transients**
  - **Contributing factors are cycle-to-cycle and cylinder-to-cylinder variations in combustion, mixing, and EGR**
  - **Spike avoidance requires rapid sensing and feedback control (not currently available)**

# Experimental results reveal the potential benefits of higher EGR rates

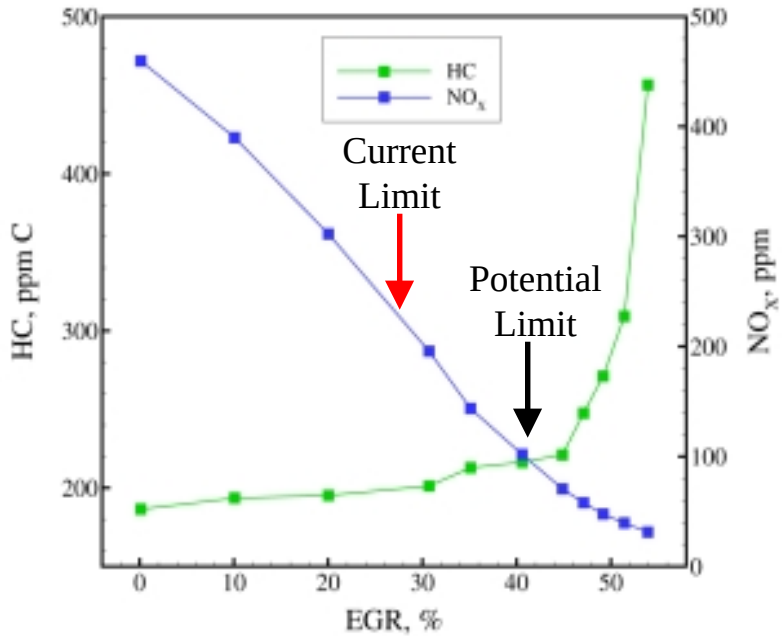
**DIATA Experiments**

**1500 rpm, 2.6 bar BMEP**




**VW Experiments**

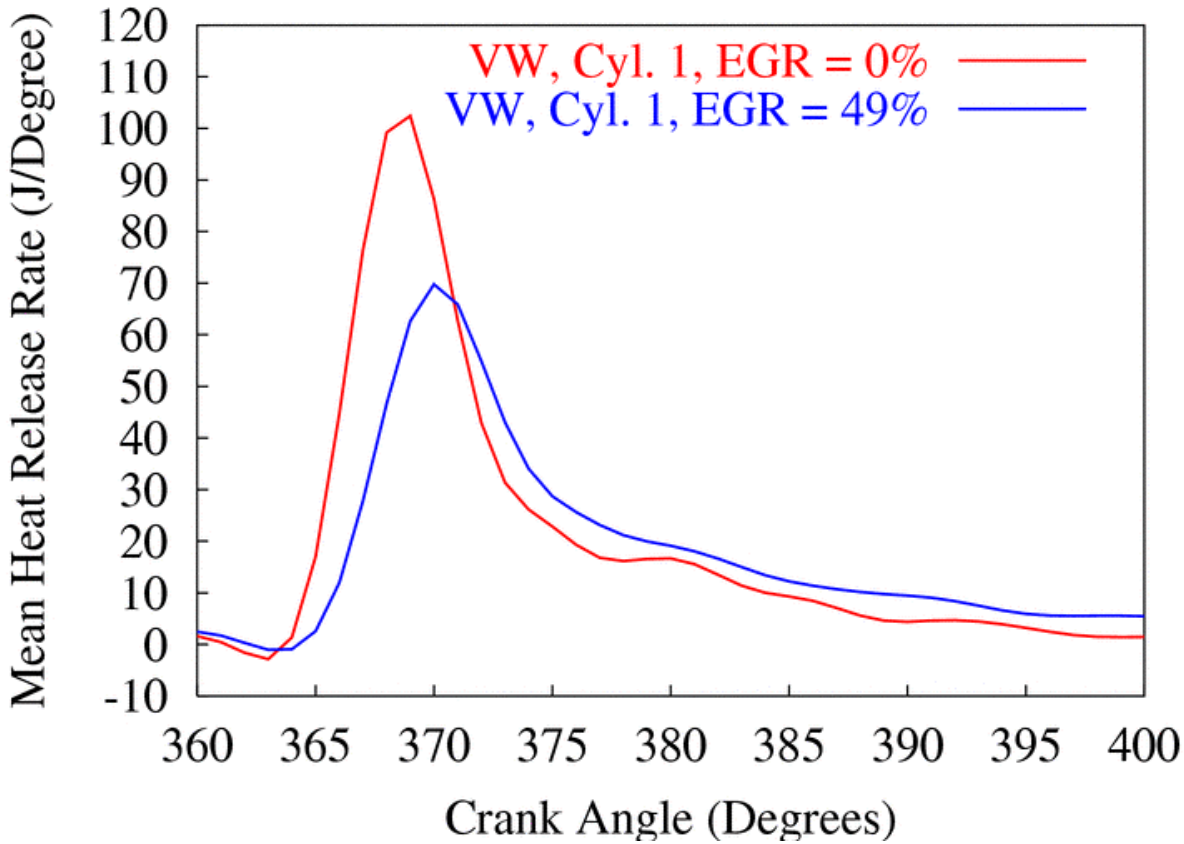
**1200 rpm, idle**



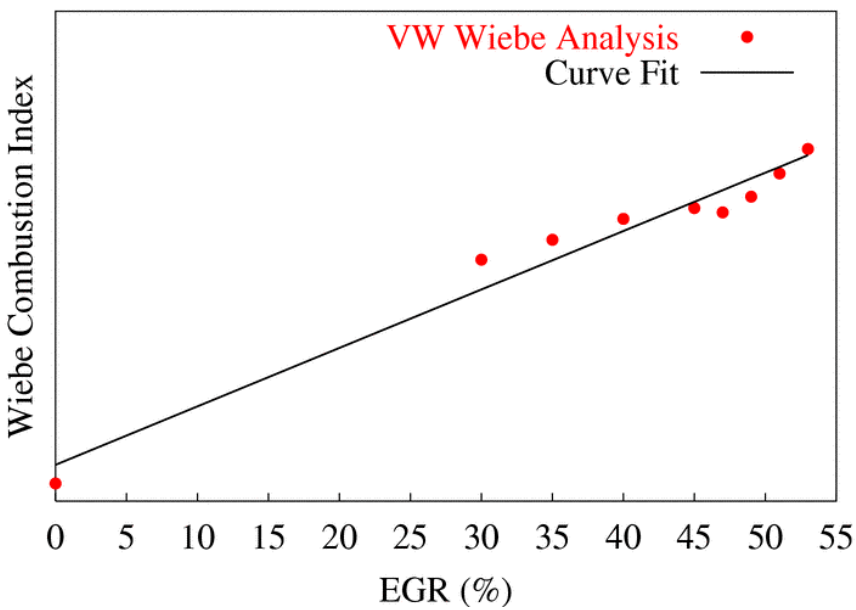
# A combustion diagnostic is needed for active feedback control

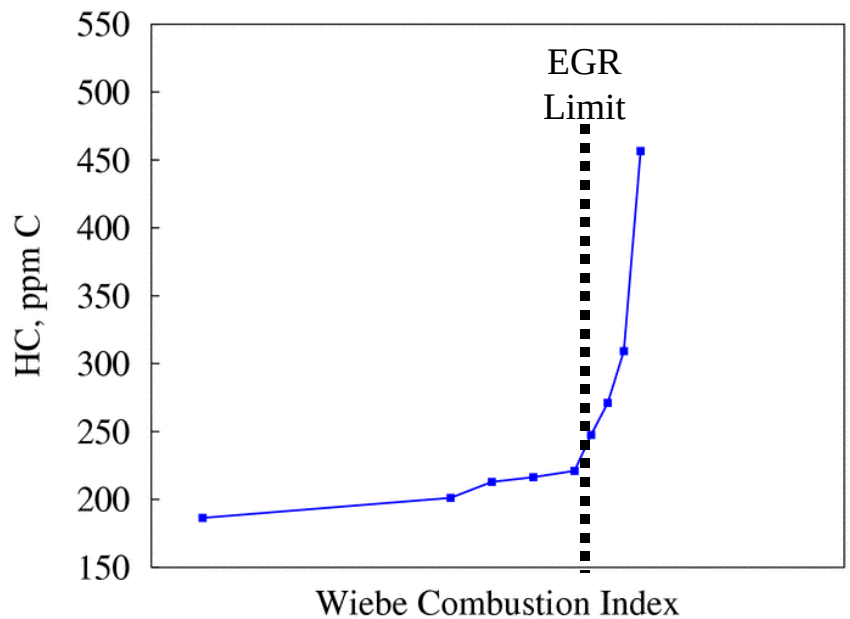
- **Approach:**
  - **Develop a virtual sensor using readily available signals to detect combustion quality**
  - **Develop diagnostics/control logic that anticipates/detects emissions spikes and makes counteractive feedback adjustments**
- **Methodology:**
  - **Correlate in-cylinder pressures, emissions, and existing engine sensors with data from ORNL and Ford**
  - **Simulate diesel combustion with transients at high EGR using GT Power spray combustion model**
  - **Fit experimental data with physically-based Ford Wiebe model to understand interaction of combustion phases**
  - **Combine data analysis and modeling to guide development of feedback control strategies (e.g., fuel injection modulation)**

# Late-stage combustion contributes strongly to emissions at high EGR levels

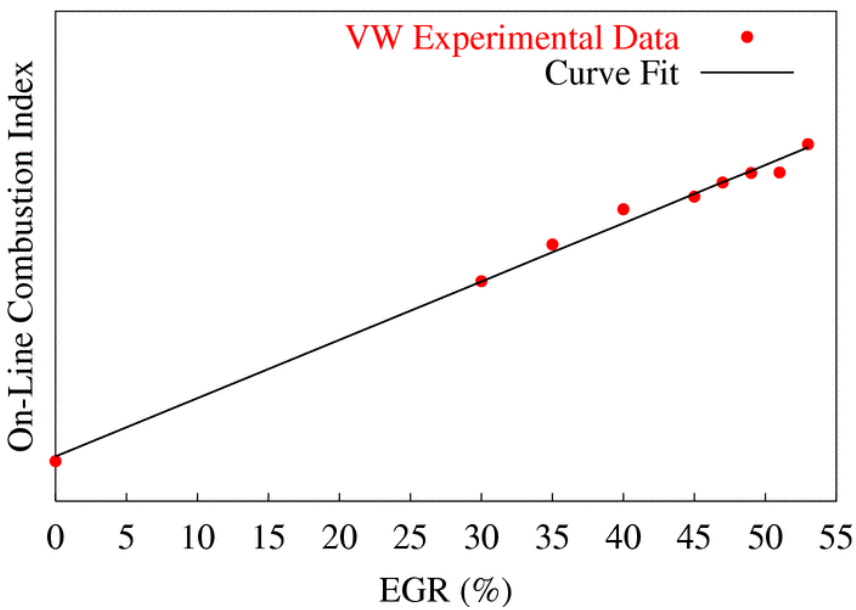


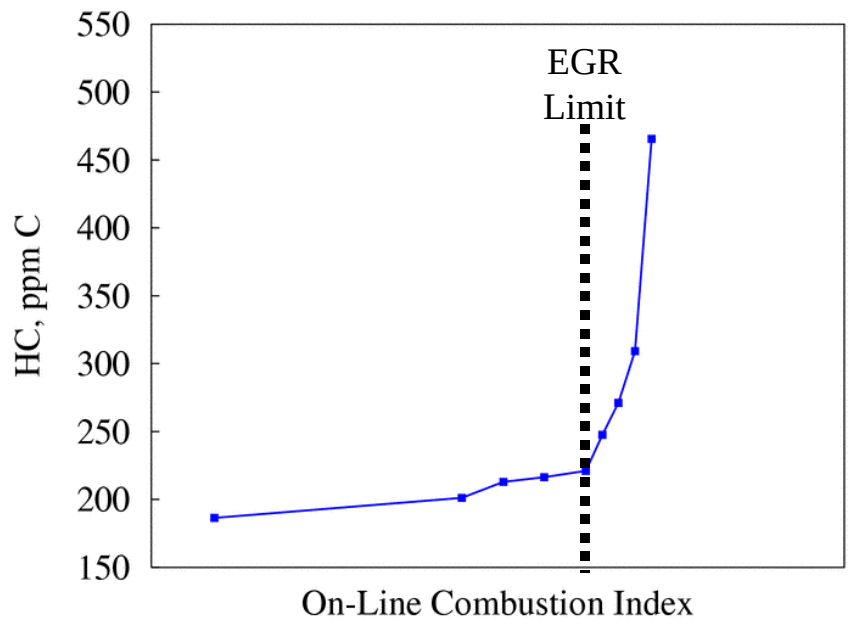
# Wiebe analysis reveals correlation between late-stage combustion and emissions



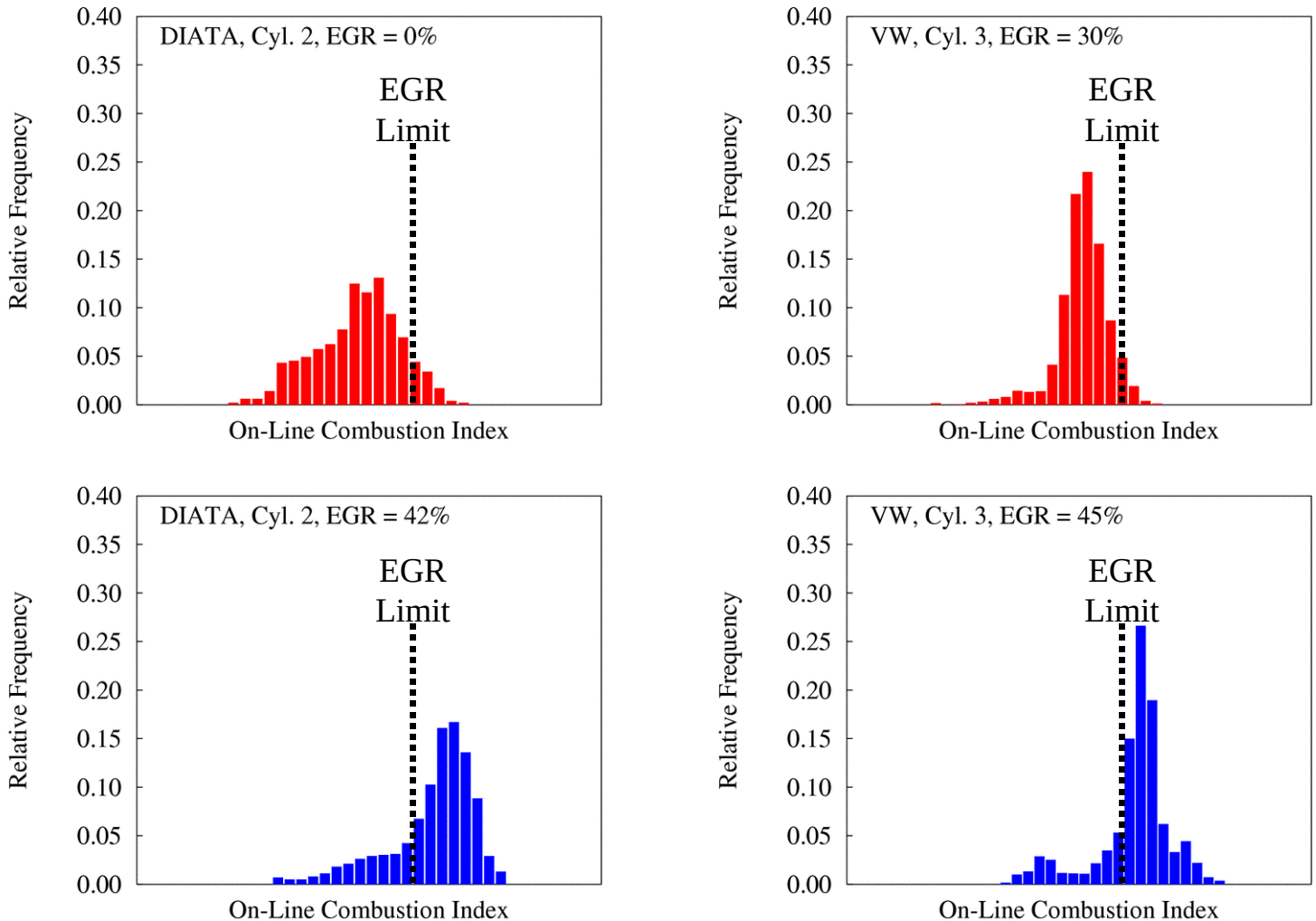



# Such correlations can be used to construct an on-line engine diagnostic (virtual sensor)



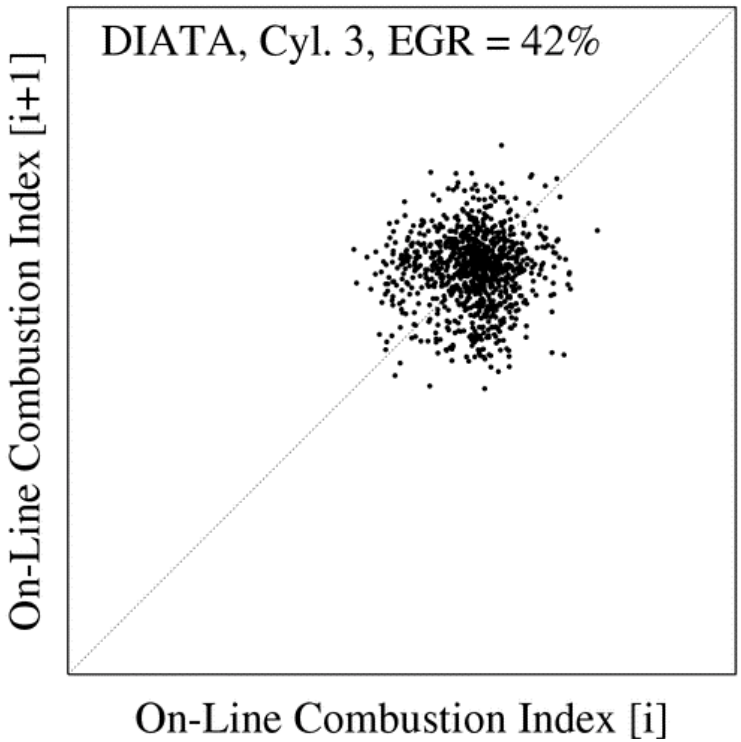
# Cyclic variations provide information that is not available from mean combustion statistics

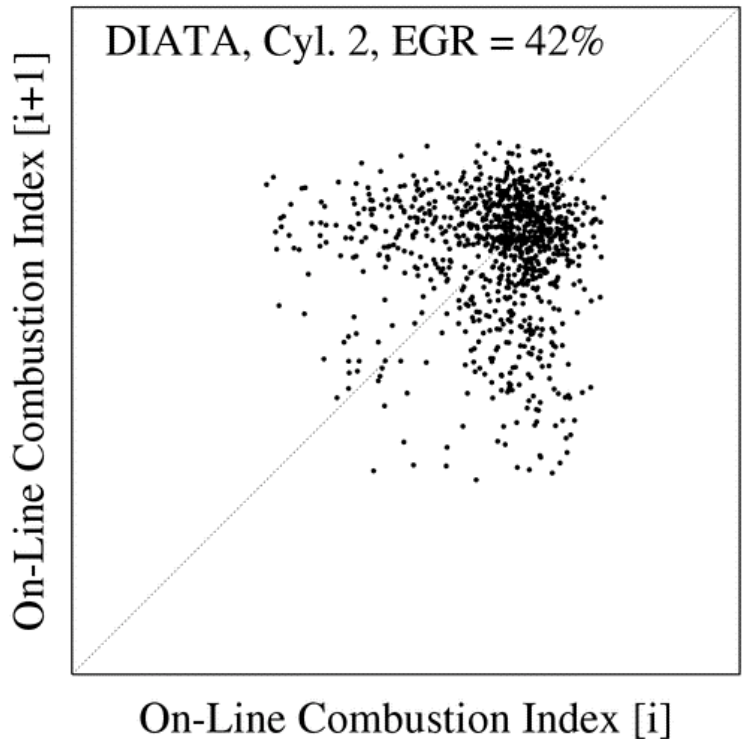


# Engine data analysis reveals three types of combustion variations

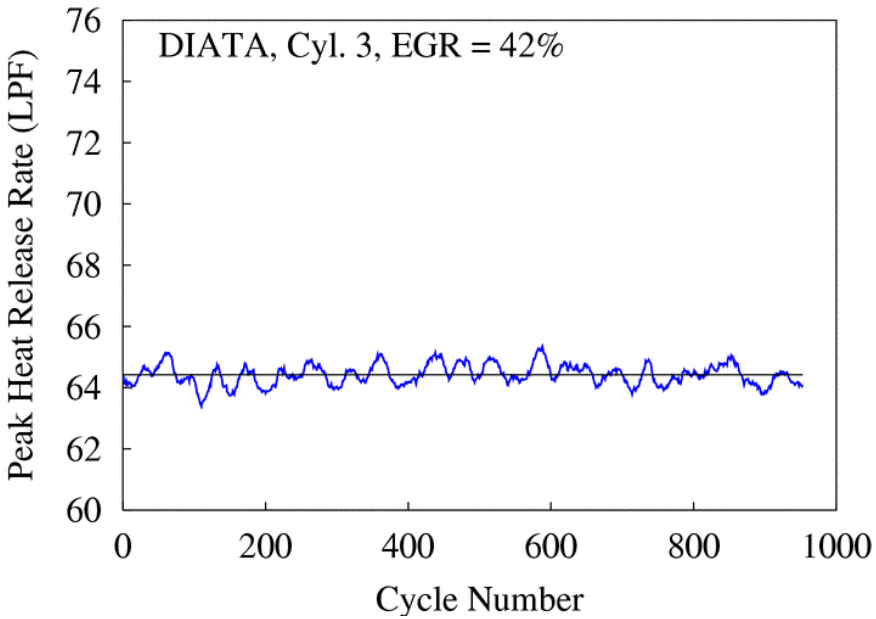
- **Cylinder-to-Cylinder Imbalances**
  - **Different cylinders have consistently different combustion behavior, emissions**
- **Slow Drift**
  - **Non-stationary heat release, combustion quality at high EGR levels under otherwise steady-state conditions**
  - **Drift varies from cylinder to cylinder over 10-100 cycles**
- **Cycle-to-Cycle Variations**
  - **Combustion quality or heat release change over one cycle**

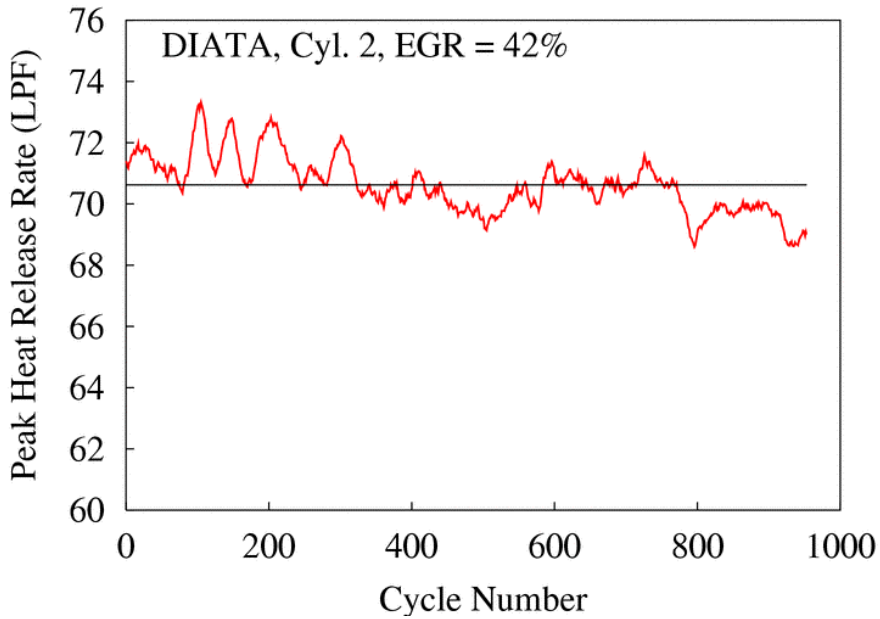
# Cylinder-to-cylinder EGR variations create long time scale combustion imbalances



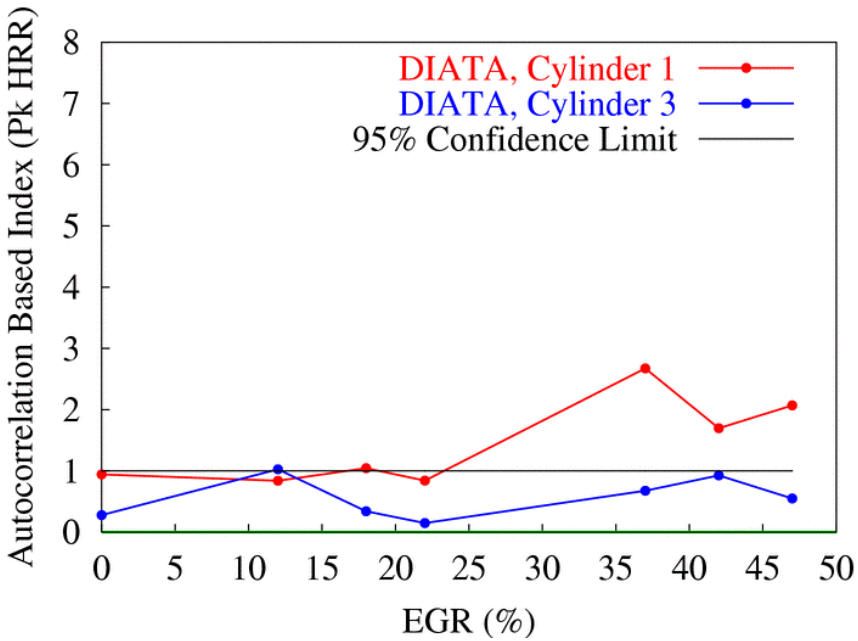



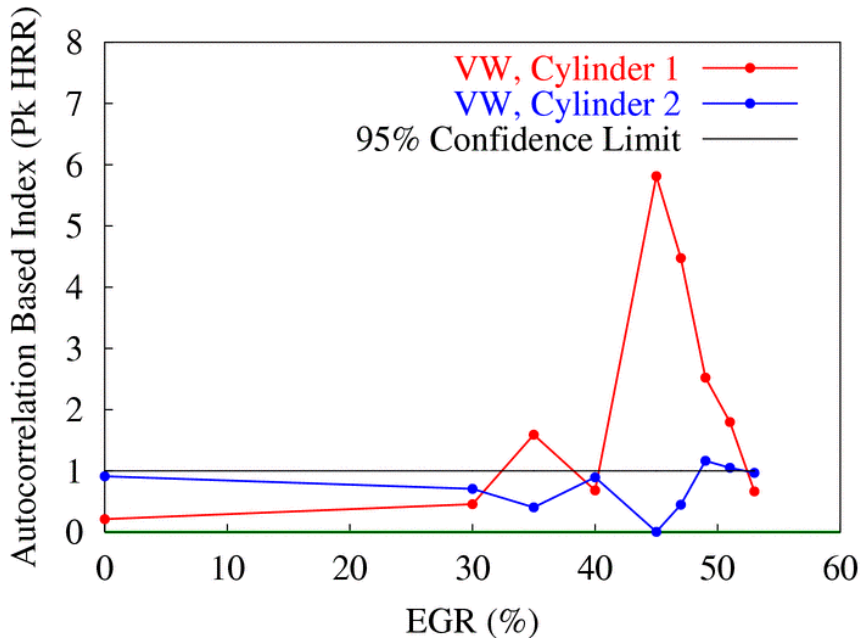
# Slow drift becomes more pronounced near the critical EGR limit for emissions



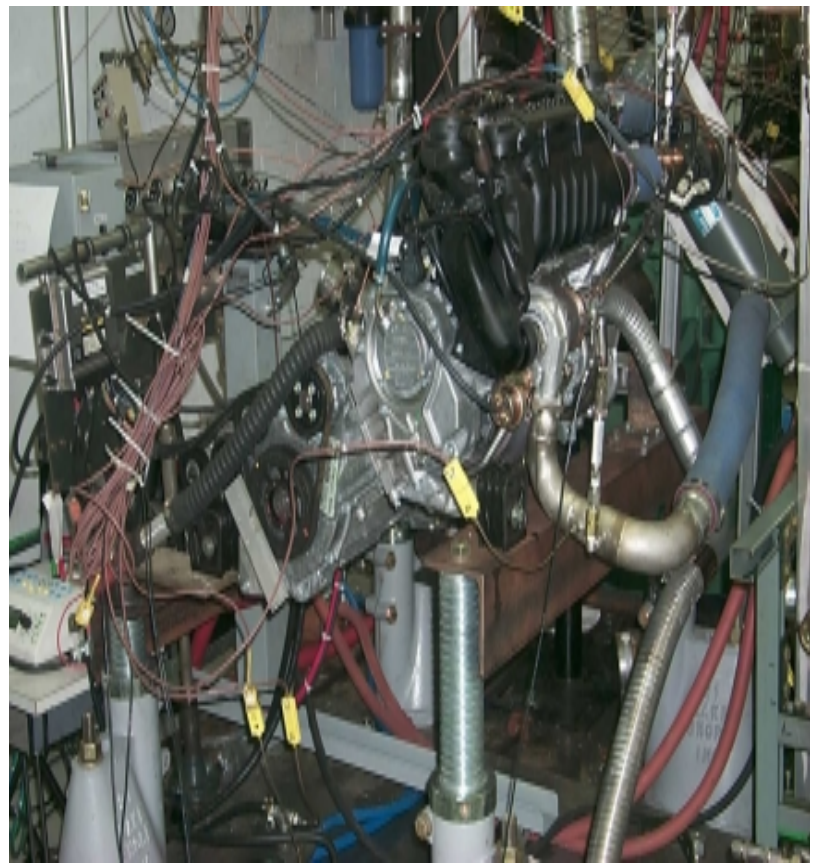
# Cycle-to-cycle combustion interactions also appear to be more pronounced at high EGR



# Hardware efforts have focused on preparing for additional experiments this summer

- Mercedes 1.7-L, turbocharged, 4-cylinder, common rail engine
- Test-stand-mounted with eddy-current dynamometer
- Crank-angle resolved cylinder pressure, crank-shaft speed
- Full-pass engine control
- Emissions
  - High-Speed
    - Cambustion fast FID (HC)
    - Cambustion fast NO (NOx)
    - DPS (PM size distribution)
  - Low-Speed
    - TEOM (PM mass)
    - SMPS (PM size distribution)



# Mercedes 1.7-L experiments will validate virtual sensor and potential control concepts

- **Experimental Goals:**
  - **Confirm virtual sensor detection of emissions variations between cylinders and examine robustness of virtual sensor**
  - **Identify source of slow drift in one or more cylinders**
  - **Identify correlation between cycle-to-cycle variations and emissions**
- **Experimental Approach:**
  - **Measure HC (fast) in different exhaust runners and EGR (slow) levels at five mode points under steady-state conditions**
  - **Create an EGR disturbance to determine how long the combustion variation persists and if it can be controlled**
  - **Investigate various fuel injection control strategies for potential feedback**

# Accomplishments and Future Plans

- **Data Analysis**
  - **Identified diagnostic that could be used to make cycle-resolved combustion quality measurements and provide active feedback**
  - **Identified three types of combustion variations that must be accounted for in the diagnostic and control actions**
- **Commissioned Rapid Prototype Engine Control System (RPECS) from SwRI**
  - **Powerful tool for engine/combustion R&D (full-pass control)**
  - **Re-engineered software and algorithms to emulate Mercedes 1.7-L ECU at steady-state conditions with the added ability to modify fuel and EGR calibrations**
- **FY 2002 Plans**
  - **Develop control strategies on the Mercedes engine using the virtual sensor in FY02**