NASA nvPM Test

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PMTG MEASURE ahg call
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Overview

- Test period: 19-27 October 2016
- Location: NASA Glenn Research Center, Cleveland, OH
- Emissions Source: NASA 9 point Lean Direct Injection (LDI) combustor
- Test Matrix:
  - Measurements were made at a combination of T3 and P3 settings for various FAR values
    - Data acquired for 39 test points over 3 days of testing
  - Gaseous emissions
    - Undiluted: [NO\textsubscript{x}, NO, CO, UHC, CO\textsubscript{2}] were measured by NASA
    - Diluted: [CO\textsubscript{2}] were measured by NASA and MST on their respective systems
  - PM emissions (number, mass, size, composition) were measured using the NASA system and North American Mobile Reference System
- Fuel samples were collected
Objectives

• Investigate the influence pressure and temperature variations on nvPM emissions

• Compare nvPM emissions measured using NASA system with North American Mobile Reference System
NASA 9 point Lean Direct Injection (LDI) combustor
Test Hardware: 9 point LDI

Woodward Simplex fuel nozzles
9 injection points (60° air swirlers and fuel nozzle)
- Pilot = 1 injection point
- Main 1 = 4 injection points
- Main 2 = 4 injection points

$F_{NUS} = 2.9$ for 9-pt LDI
$A_{Cd} = 1.3\text{ in}^2$
## Instruments

**NASA System**

- **Number:**
  - 3775 CPC (with thermal denuder)
  - 3775 CPC

- **Mass:**
  - AVL MSS Plus
  - ARI CAPS-PM$_{ex}$

- **Size:**
  - TSI SMPS
  - TSI EEPS

**North American Mobile Reference System**

- **Number:**
  - AVL APC (with catalytic stripper)

- **Mass:**
  - AVL MSS
  - ARI CAPS-PM$_{ex}$
  - Artium LII-300 (not available for test)

- **Size:**
  - Cambustion DMS500

- **Composition**
  - ARI CToF-AMS
Gaseous Emissions Idle

Engine Idle Condition 100 PSIA
EICO vs Inlet Temperature

Inlet Temperature (C)
Gaseous Emissions Cruise

Engine Cruise Condition 150 PSI
EICO VS. Inlet Temperature
Preliminary nvPM data Analysis

• nvPM concentration data was reduced and averaged over each test point

• Dilution corrected nvPM number and mass concentration data was analyzed as a function of T3 for various P3 and FAR values
nvPM Number - Idle

\[ y = -6917.3x^2 - 28591x + 9E+06 \]
\[ R^2 = 0.9936 \]

\[ y = -863.73x^2 - 76454x + 4E+06 \]
\[ R^2 = 0.9649 \]
nvPM Number - Cruise

\[ y = 730.19x^2 - 86718x + 3E+06 \]
\[ R^2 = 0.9301 \]

\[ y = 1998.7x^2 - 95714x + 2E+06 \]
\[ R^2 = 0.9645 \]
nvPM Mass - Idle

\[ y = -5 \times 10^{-5}x^2 - 0.0007x + 0.086 \quad R^2 = 0.9919 \]

\[ y = -2 \times 10^{-5}x^2 - 0.0006x + 0.0446 \quad R^2 = 0.9834 \]
nvPM Mass - Cruise

The graph shows the nvPM dilution corrected mass concentration (mg/m$^3$) as a function of inlet temperature (°C). The data is differentiated by FAR values: FAR = 0.024 (blue circles) and FAR = 0.028 (red circles).
Summary

• Successfully achieved test objectives

• Low nvPM number and mass concentrations:
  – at high T3-P3 settings
  – at fuel rich conditions

• Trends in nvPM number easier to track
  – higher signal to noise ratio

• Strong influence of T3 on nvPM number and mass
  – Smaller influence of FAR and P3

• Need additional data to develop correction factors for ISA