

# **Aircraft Particle Emissions eXperiment (APEX)**

**A Multi-Agency  
Commercial Aircraft Emission Characterization  
and  
Technology Demonstration Experiment**

**Dr. Chowen Chou Wey  
ARL/NASA GRC**

# Objectives

**To characterize particle and trace gas precursor species from the NASA aircraft DC-8 with CFM56-2 engines at the engine exit plane as well as at selected down stream locations to advance the understanding of particle emissions and their evolution in the atmosphere from a current in-service turbofan engine**

# Data Usage

## NASA

- To define the physical and chemical properties of particle emissions (including transient due to throttle change and start-up) from the engine at the exit plane as a function of engine operating parameters and fuel properties
- To define the physical and chemical properties of particle emissions from the aircraft at selected downstream locations to advance the knowledge of particle transformations in the atmosphere during operations in and around airports

## EPA

- To develop fine particle mass emission factors (indices) and chemical source profile for the CFM-56 engine
- To assess difference in sampling methodology, i.e. exit plane measurement with dilution at sampling probe tip vs measurement at 30m downstream with natural dilution

## DoD

- To assess instrumentation and sampling methodologies for development of turbine engine particle emissions measurement protocol

## FAA

- To help airports in determining if their operations comply with National Ambient Air Quality Standards (NAAQS) for PM-2.5

# Team

**Sponsors:** NASA  
EPA  
DOD

**Participants:** NASA (DFRC, GRC, LaRC), EPA, FAA,  
DoD (AEDC, NAVAIR, NFESC, WPAFB),  
Aviation Industry (GE, Boeing, PW),  
Research community (ARI, MIT, PM  
UCR, UMR)

**Manager:** Dr. Chowen Chou Wey  
NASA GRC

# Fuels

## 1. Base Fuel

**JP8 from Edwards AFB**

## 2. High Sulfur Fuel

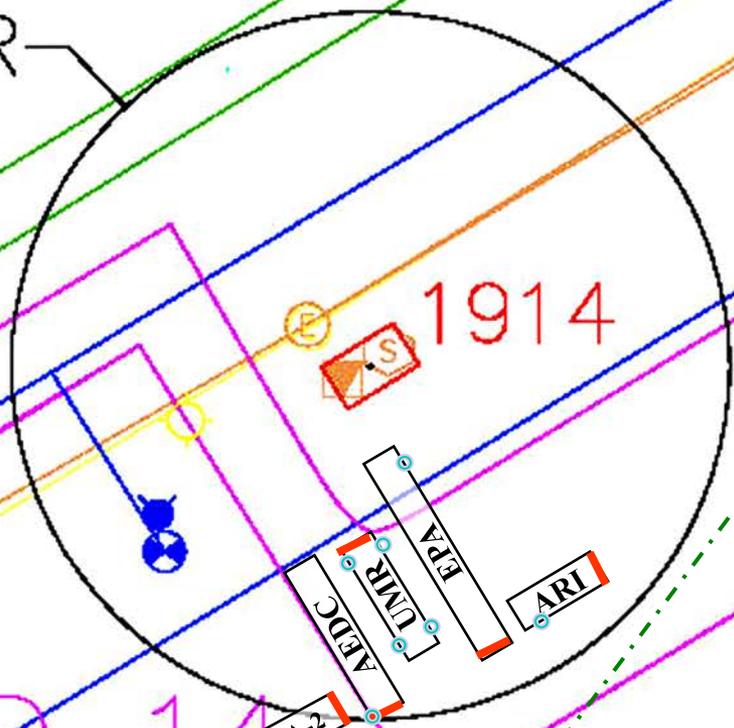
**doped base fuel with additives to raise sulfur content by approximately 1000 ppm**

## 3. High Aromatic Fuel

**Jet A with high aromatic HC content (~ 22%; typical 16 - 18%)**

○ Electrical access  
— Back Doors

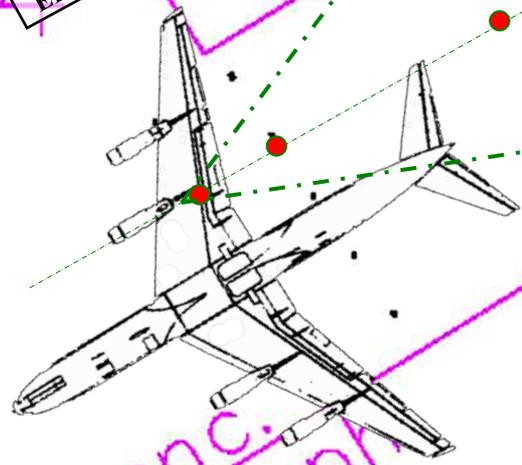
100'R



PAD 14

Asph.  
Conc.

3 Sampling Rakes



Asph.  
Dirt





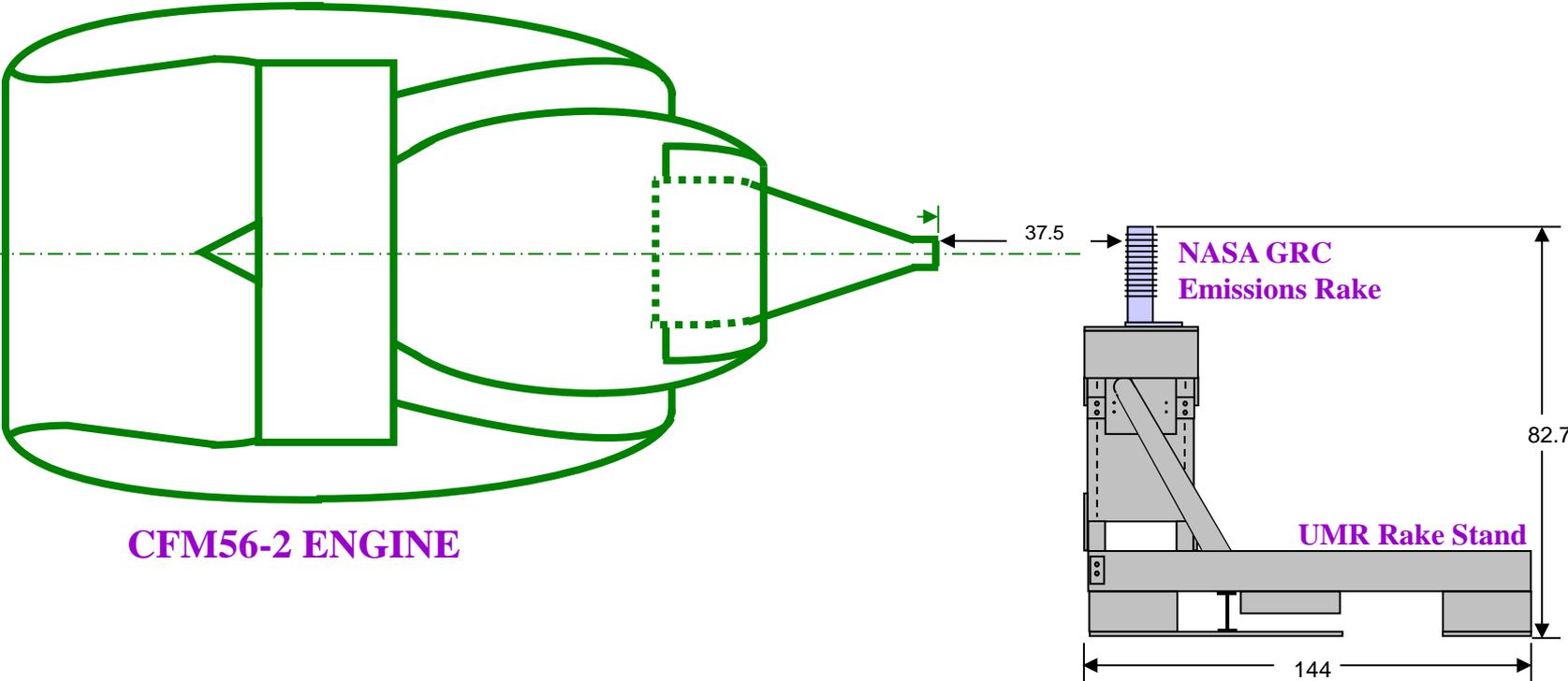








# Sampling Probe Stand



CFM56-2 ENGINE

NASA GRC  
Emissions Rake

UMR Rake Stand

37.5

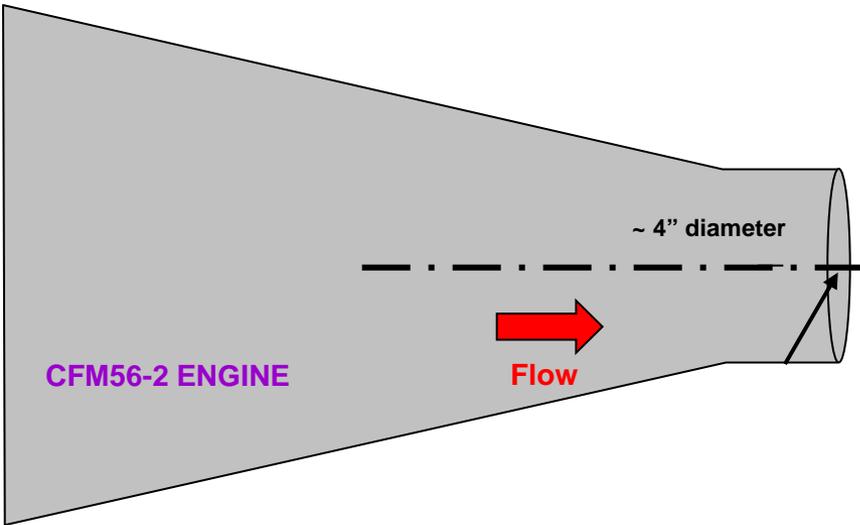
82.7

144

All dimensions in inches

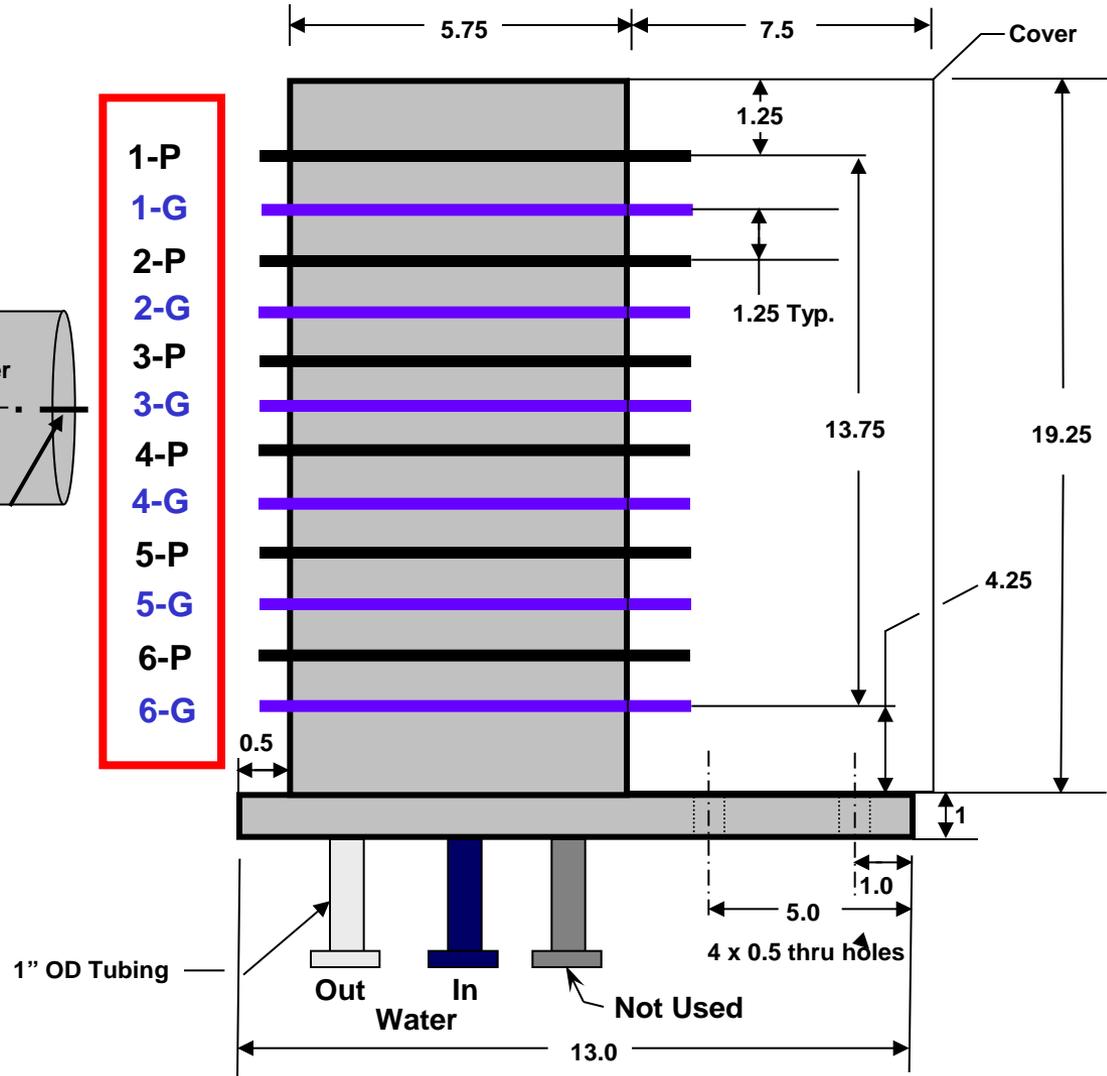


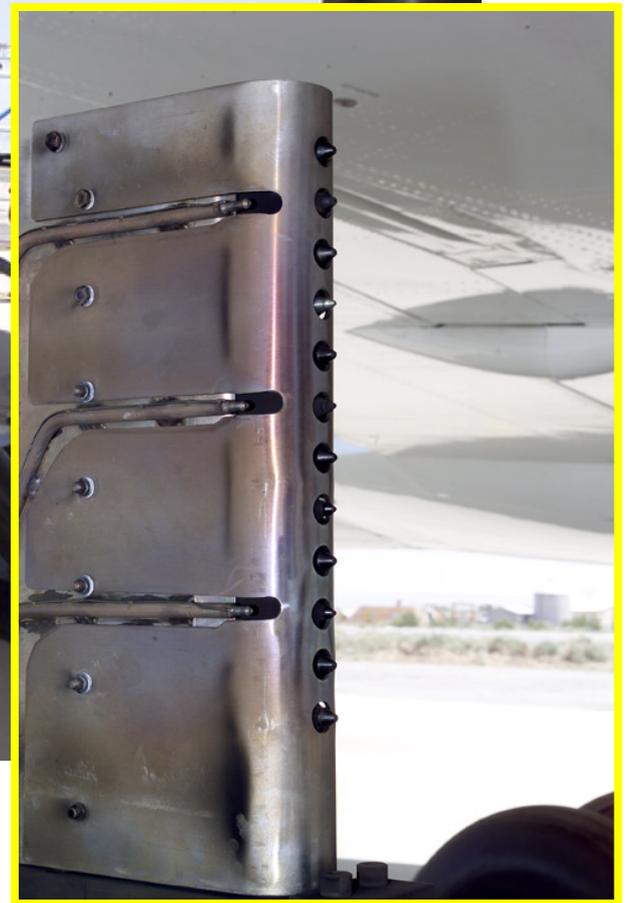
# Sampling Probe Configuration

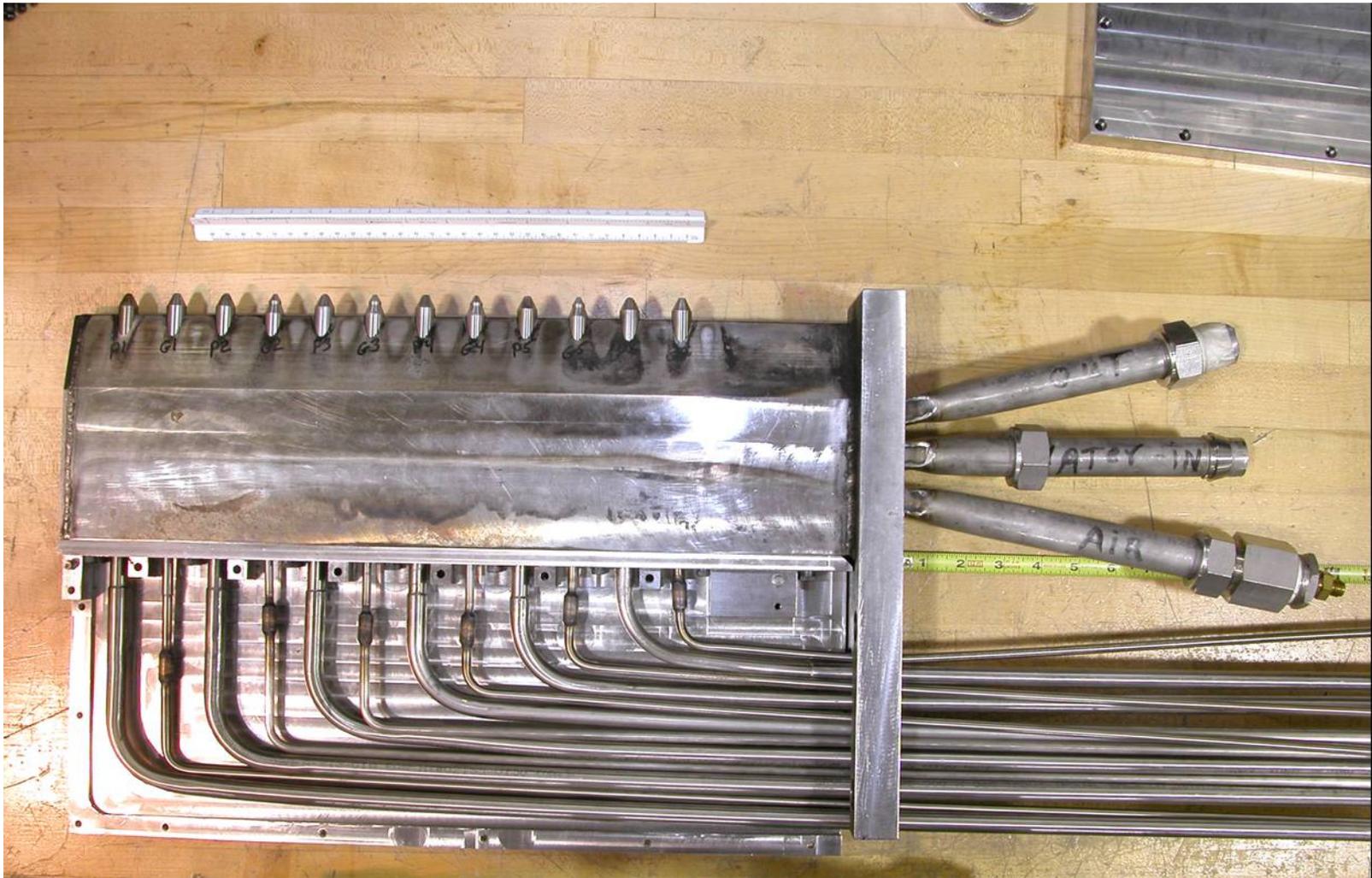


- 1-P
- 1-G
- 2-P
- 2-G
- 3-P
- 3-G
- 4-P
- 4-G
- 5-P
- 5-G
- 6-P
- 6-G

G		Gas Emission
P		Particulate
All dimensions in inches		





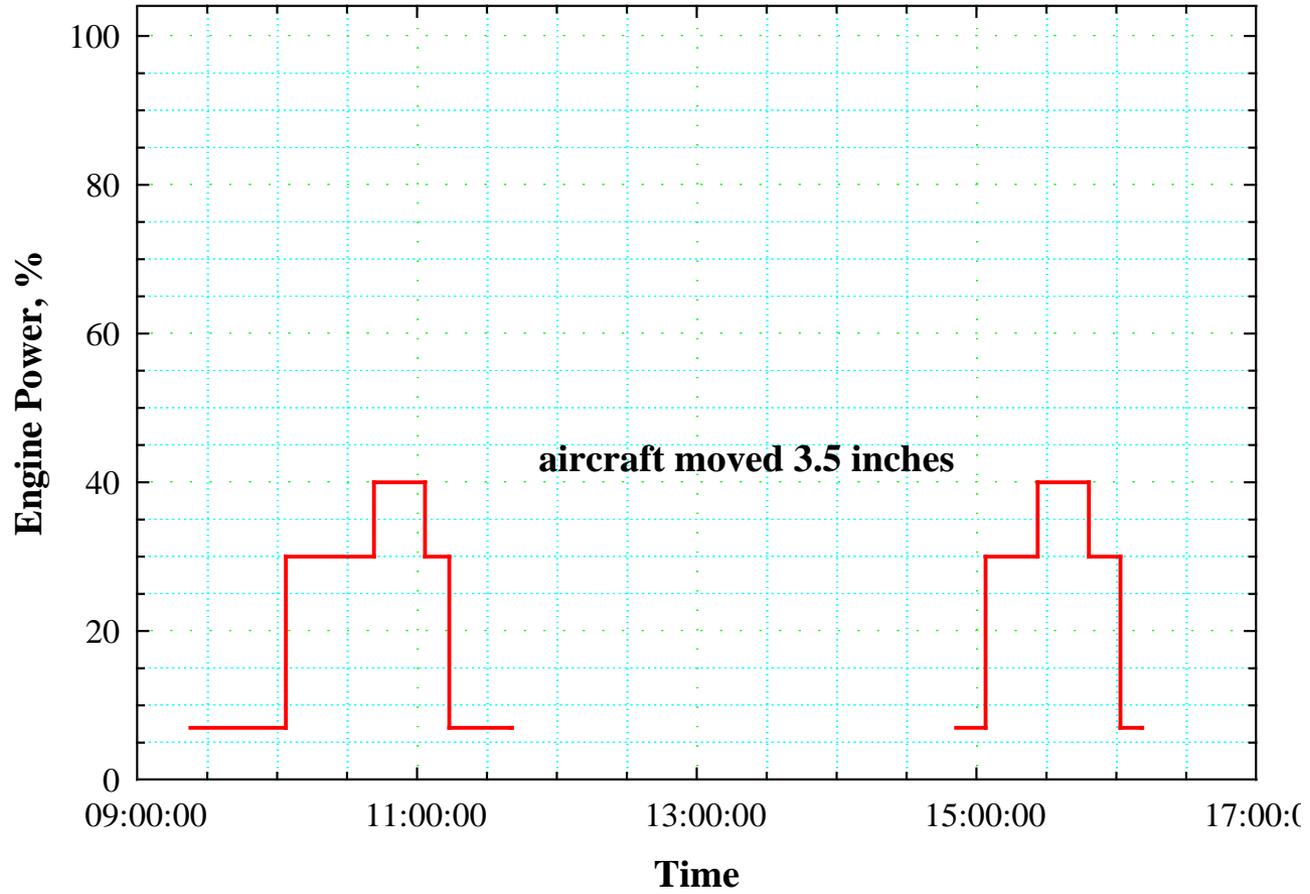


# Test Log

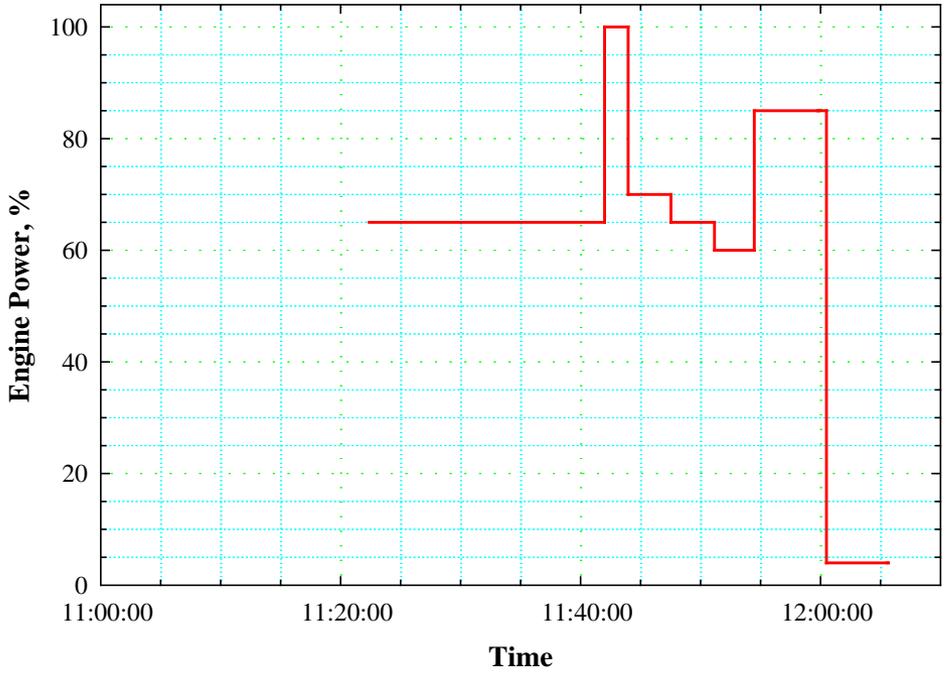
- **Apr 15–19 Set-up, Calibration**
- **Apr 20 Check-out, low power conditions**
- **Apr 21-22 Fix probe arm, Anchor sampling lines & cables**
- **Apr 23 Mapping, low power conditions**
- **Apr 24 Check-out, high power conditions**
- **Apr 25 Mapping, high power conditions**
  - EPA #1, Base Fuel**
- **Apr 26 EPA #2, Base Fuel**
  - NASA Base Fuel #1 & #2, low power conditions**
- **Apr 27 NASA Base Fuel #1 & #2, high power conditions**
  - NASA High Sulfur Fuel #1**
- **Apr 28 NASA High Sulfur Fuel #2**
  - NASA High Aromatic Fuel #1**
- **Apr 29 NASA High Aromatic Fuel #2**
  - EPA #3, High Aromatic Fuel**
- **Apr 30 Tear-down**

# Low Power Conditions Mapping

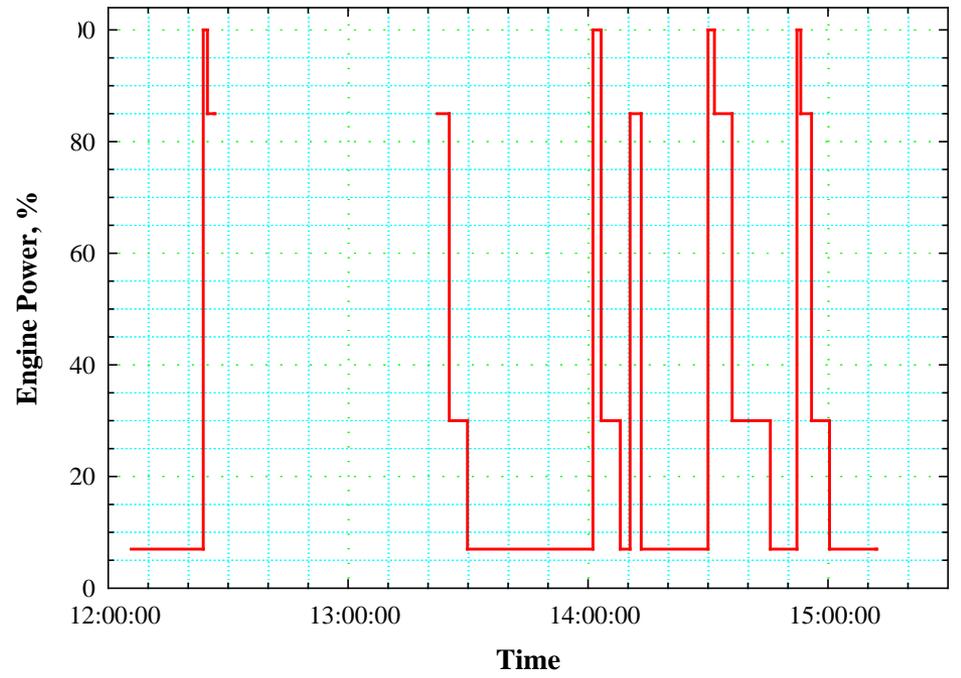
4/23/2004



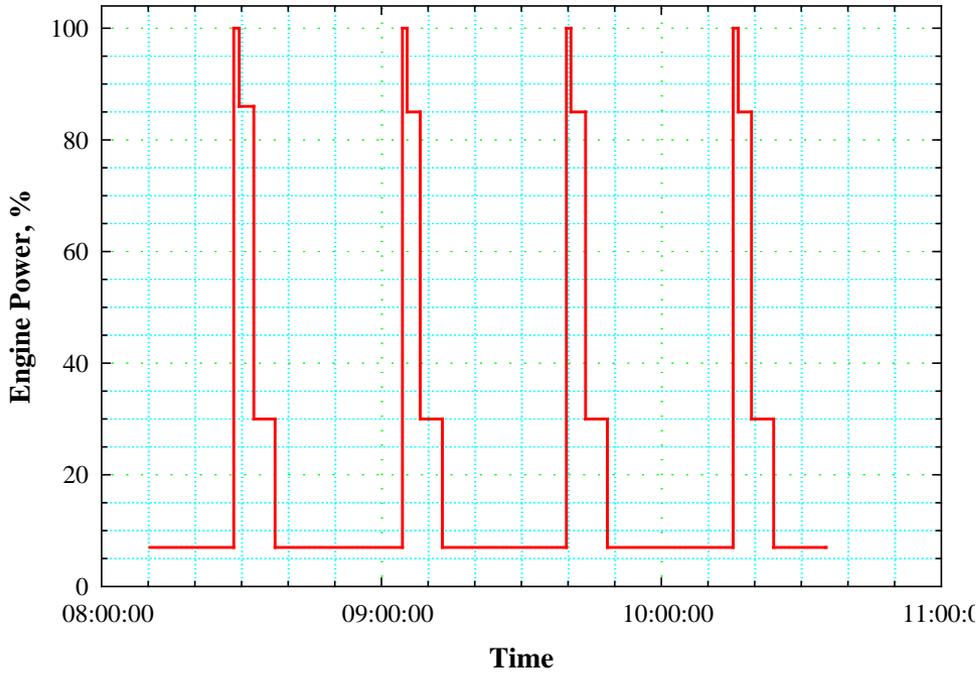
**High Power Mapping**  
4/25/2004



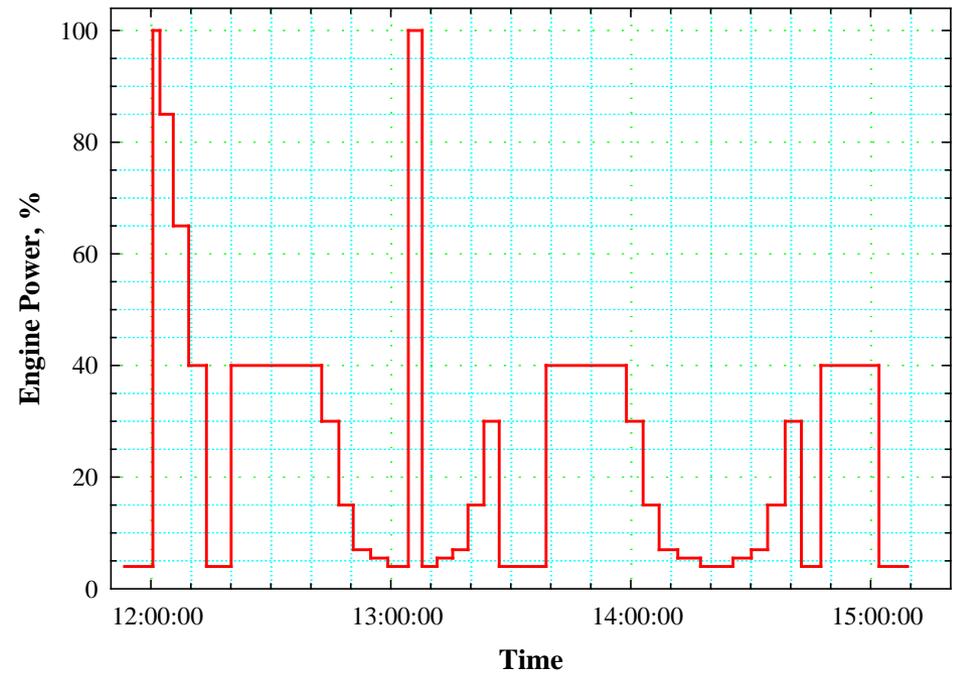
**EPA Sequence #1**  
4/25/2004



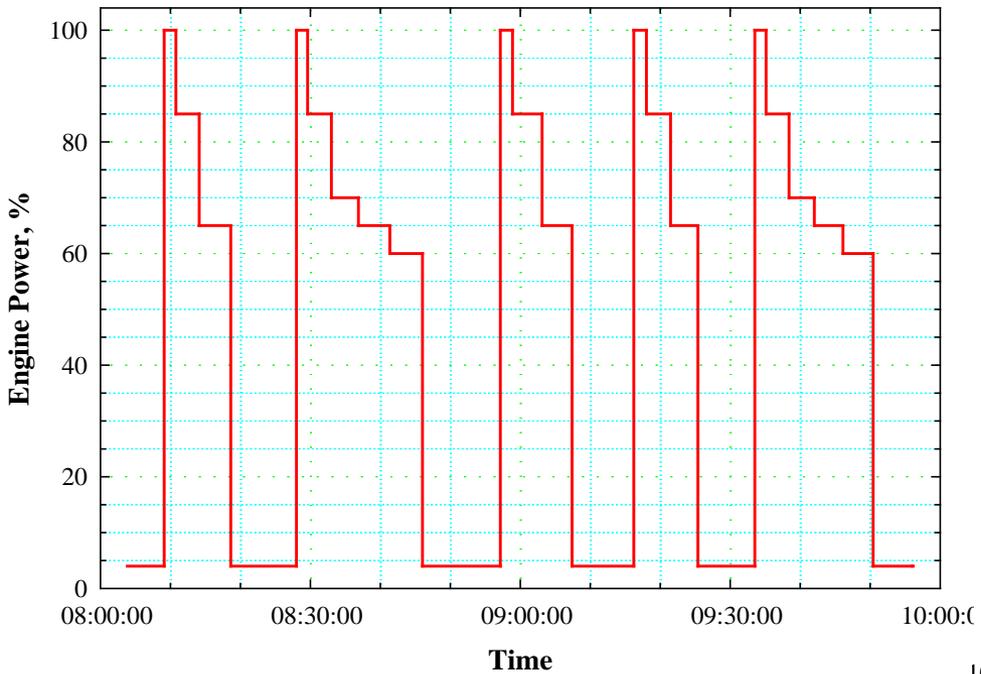
**EPA Sequence #2**  
**4/26/2004**



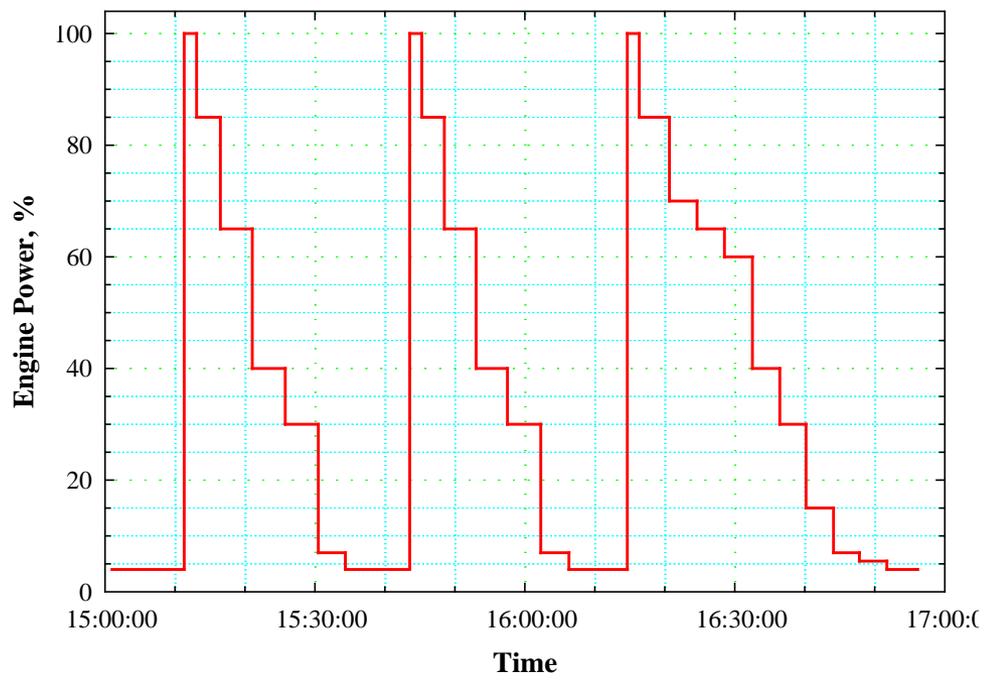
**NASA Base Fuel Sequence #1 & #2 Low Power Conditions**  
**4/26/2004**



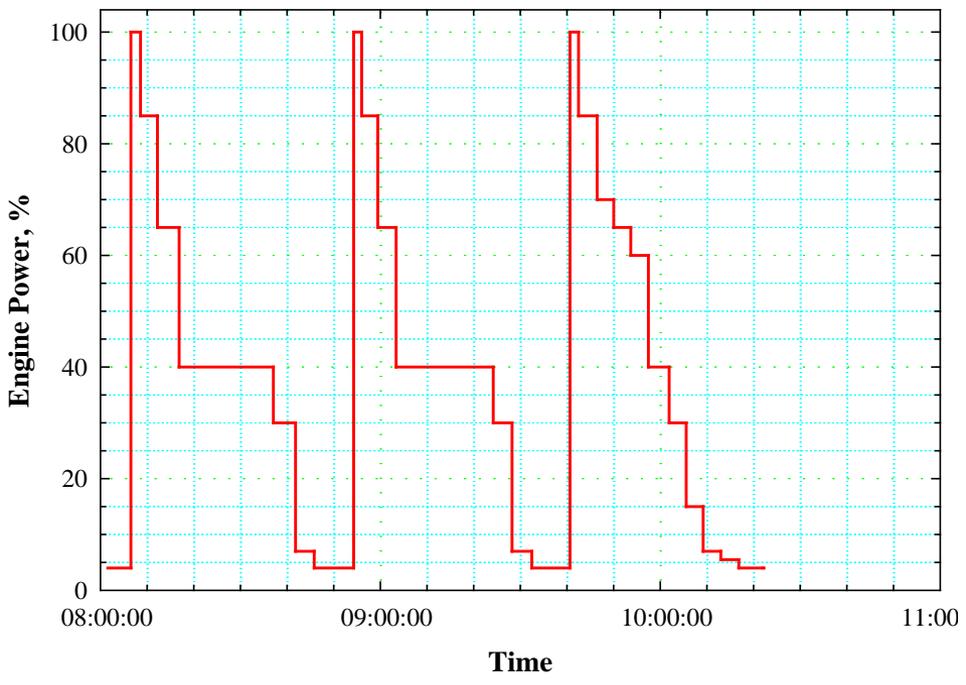
**NASA Base Fuel Sequence #1 & #2 High Power conditions**  
**4/27/2004**



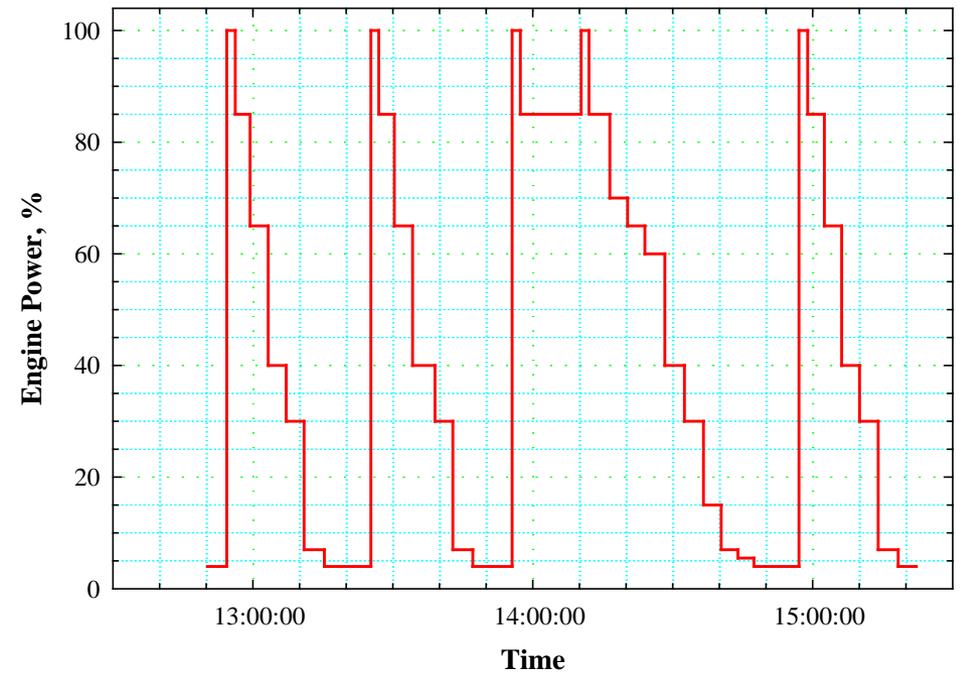
**NASA High Sulfur Fuel Sequence #1**  
**4/27/2004**



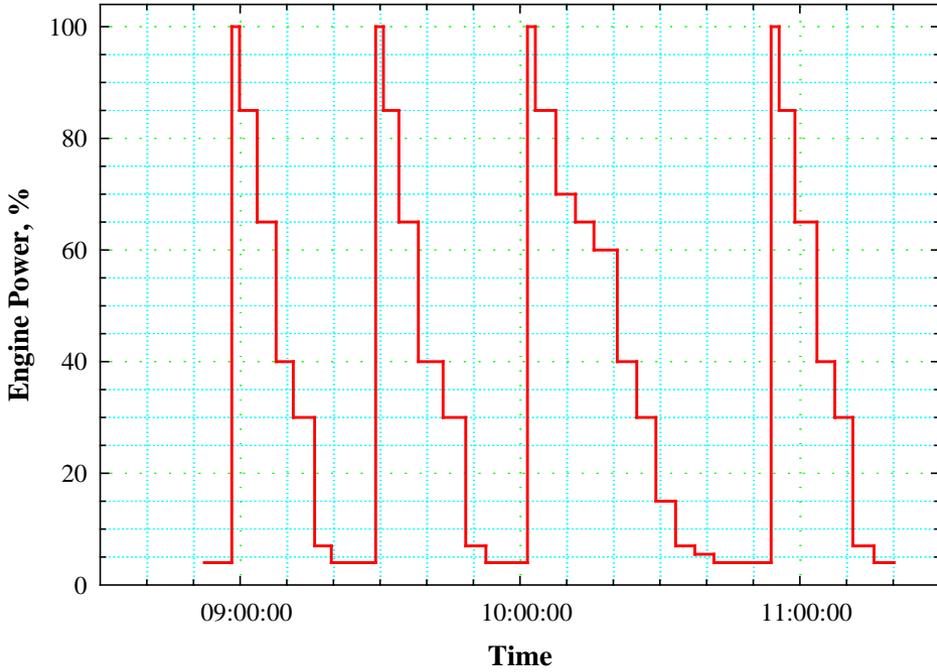
**NASA High Sulfur Sequence #2**  
**4/28/2004**



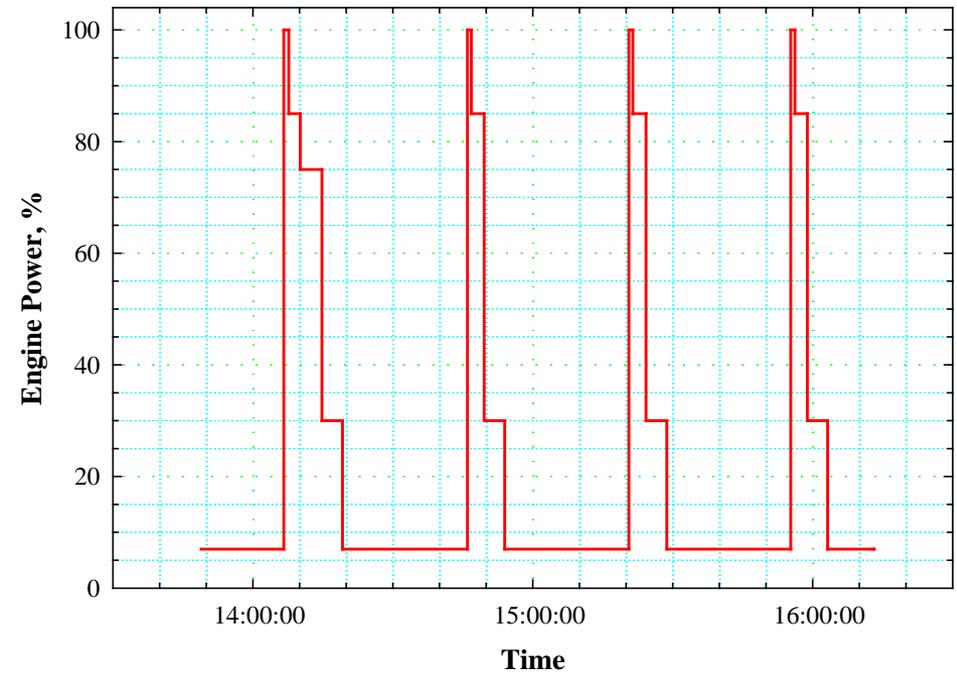
**NASA High Aromatic Sequence # 1**  
**4/28/2004**



**NASA High Aromatic Sequence # 2**  
**4/29/2004**



**EPA Sequence #3 - High Sulfur Fuel**  
**4/29/2004**







# Measurements Performed

## Aerodyne Research, Inc.

- NO, NO<sub>2</sub>, HONO, H<sub>2</sub>CO, C<sub>2</sub>H<sub>2</sub>, CO, N<sub>2</sub>O, CO<sub>2</sub>
- Non-refractory aerosol size, selected number density, and composition
- Various Oxy-VOC and aromatics

## Arnold Engineering Development Center

- CH<sub>4</sub>, HCHO, C<sub>2</sub>H<sub>4</sub>, CH<sub>3</sub>OH, COOH, SO<sub>2</sub>, H<sub>2</sub>O, CO, CO<sub>2</sub>, N<sub>2</sub>O, NO, NO<sub>x</sub>  
possible C<sub>2</sub>H<sub>6</sub>, C<sub>4</sub>H<sub>6</sub>, C<sub>2</sub>H<sub>2</sub>, CH<sub>3</sub>CHO, C<sub>7</sub>H<sub>8</sub>
- Smoke Number
- Non-volatile mass
- Total teperature

## Environmental Protection Agency

- PM mass/number concentration, particle size distribution, and total non- volatile PM
- PM elemental/organic carbon and semi-volatile organic compounds
- PM water-soluble ions and elemental composition
- Gas-phase air toxics, non-methane organics, and carbonyls
- CO, CO<sub>2</sub>, and THC in plume

# Measurements Performed (continued)

## National Aeronautics and Space Administration (NASA)

### Dryden Flight Research Center

- engine conditions
- ambient temperature, pressure, wind speed and direction, humidity

### John H. Glenn Research Center at Lewis Field

- CO, CO<sub>2</sub>, O<sub>2</sub>, NO, NO<sub>x</sub>, UHC
- CH<sub>4</sub>, HCHO, C<sub>2</sub>H<sub>4</sub>, CH<sub>3</sub>OH, COOH, SO<sub>2</sub>, H<sub>2</sub>O, CO, CO<sub>2</sub>, N<sub>2</sub>O, NO, NO<sub>x</sub>  
possible C<sub>2</sub>H<sub>6</sub>, C<sub>4</sub>H<sub>6</sub>, C<sub>2</sub>H<sub>2</sub>, CH<sub>3</sub>CHO, C<sub>7</sub>H<sub>8</sub>

### Langley Research Center

- Total CN, non-volatile CN
- Composite aerosol size distribution, non-volatile aerosol size distribution
- Black carbon absorption coeff.
- Aerosol composition: water soluble ions, EC/OC
- CO<sub>2</sub>

# Measurements Performed (continued)

## Process Metrix

- Soot total mass, mass mean diameter

## University of California - Riverside

- Speciated volatile and semi-volatile organic gases (VOCs/SVOCs), including cobonyls and
- PM mass, elemental /organic carbon, metals, and ions

## University of Missouri - Rolla

- Total number concentration, size distribution, hydration properties, Morphology
- CO<sub>2</sub>, relative humidity
- Ambient conditions

## Air Force Research Laboratory - Wright Patterson Air Force Base

- Total mass

# Data Analysis, Sharing, Publication/Presentation

## May – September

- Analyzing data

## September 14 – 15 at NASA GRC

- Data Workshop
- Limited to measurement team only
- Data inter-comparison, correlation

## November 8 – 10 at Cleveland

- NASA/EPA/FAA/DoD cosponsored meeting
- Limited to US stakeholders
- Preliminary data summary and conclusions

2005 International Symposium – special session?



