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Partners: UMR, MIT, Aerodyne Inc., AEDC, NASA, FAA, and HVL Assoc.

Center of Excellence for Aerospace Particulate Emissions Reduction Research

Mass Measurements for Gas Turbine Engine Exhaust

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Cambridge Particle Meeting

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Overview

- Regulatory requirements
- Measurement Campaigns
- Good understanding of size, number and shape
- Direct mass measurement
- Examples from recent studies
- Future Work

Growth of Commercial Air Traffic

- **PM from aircraft gas turbine engines during all phase of operation represents a unique source of a criteria pollutant as defined by the Clean Air Act**

- **Particulate matter (PM) represents a direct threat to public health and contributes to visibility degradation…**

  North Eastern States Coordinated Air Use Management, 2003

- **10 of the 50 Largest Public Use Airports in PM10 NAA/Maintenance Areas; Approximately 31 will be in PM2.5 areas…**

  DOT ACAIS Airport Database and EPA Green Book for Nonattainment Areas

- **EPA - the health costs of fine PM are hundreds of times greater than those of NOx on a per pound basis.**

Regulatory Requirements

- International Civil Aviation Organization (ICAO) requires the reporting of the “smoke number” for engine certification (SAE ARP 1179 Rev C)

- PM reduction design strategies in the last 20 years have been so effective that most current/advanced engines in operation today have virtually negligible smoke numbers throughout their operational envelope

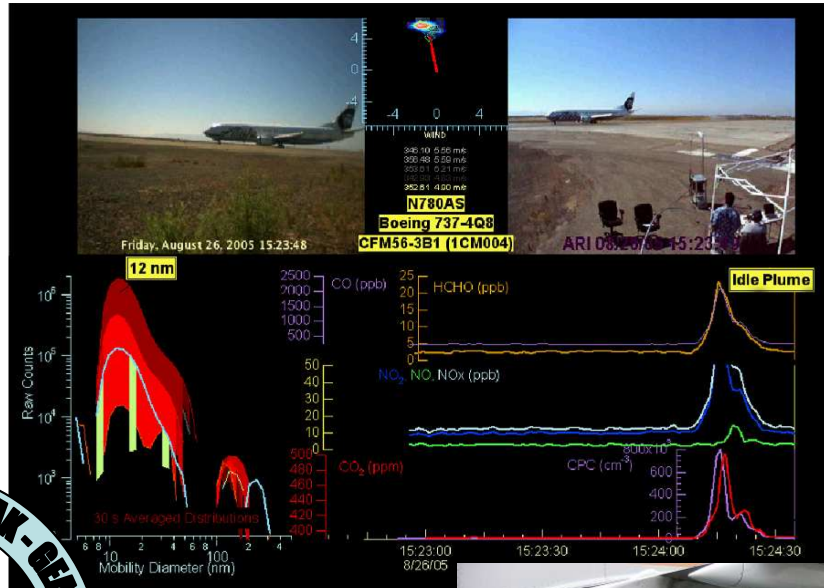
- Negligible smoke numbers, however do not ensure negligible PM emissions

Regulatory Requirements

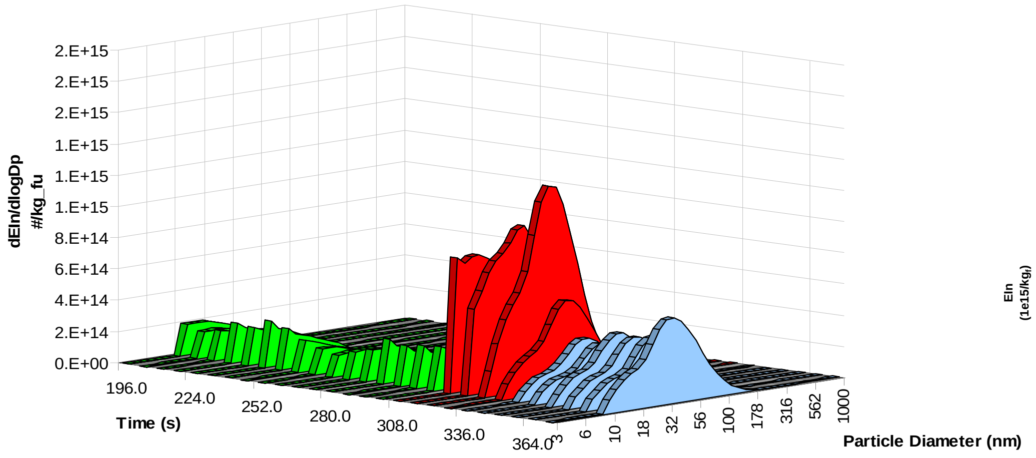
- **First Order Approximation (FOA3)**
  - ✓ CAEP developed, accepted, and supported
  - ✓ Identified scientific expressions for each driver of aircraft PM emissions…
    - ✓ non-volatile, fuel sulfur content, fuel organics

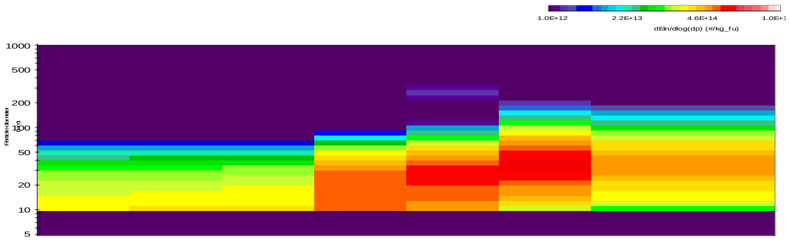
- *INTERIM METHODOLOGY*- FOA will become obsolete once a fully validated & verified database of PM EIs represents the current flying fleet is prepared
  - ✓ Measurements are the gold standard

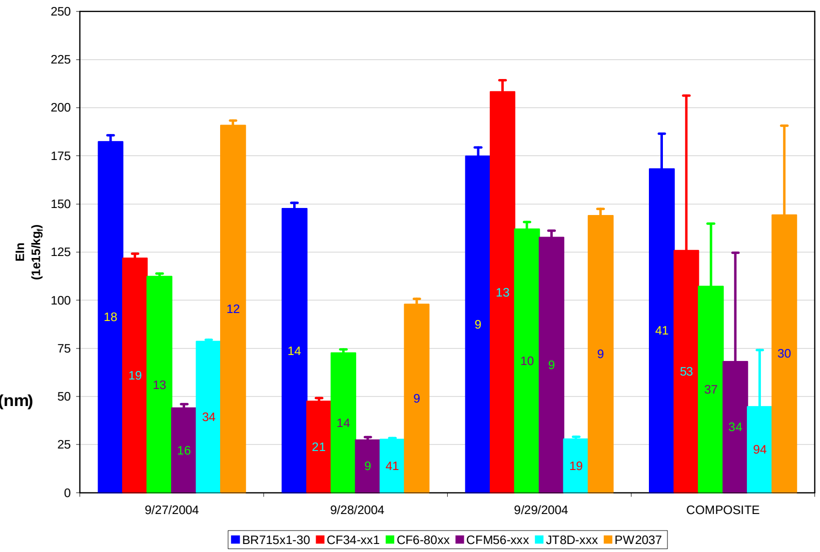
Measurement Campaigns

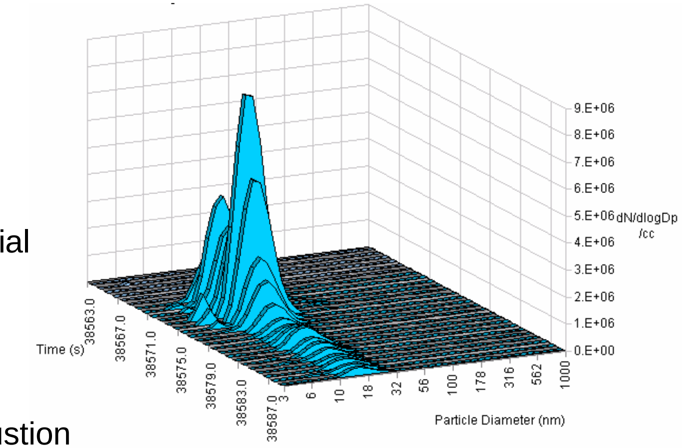


Measurements with the DMS500









Wey et al., 2007 "Overview on the Aircraft Particle Emissions eXperiment (APEX)", *accepted Journal of Propulsion & Power*

Lobo et al., 2007, "Physical characterization of aerosol emissions from a Commercial Gas Turbine Engine – Project APEX", *accepted Journal of Propulsion & Power*

Whitefield et al., 2006, "PM emissions from advected plumes at the Oakland International Airport", Transport, Atmosphere, and Climate Conference, Oxford UK

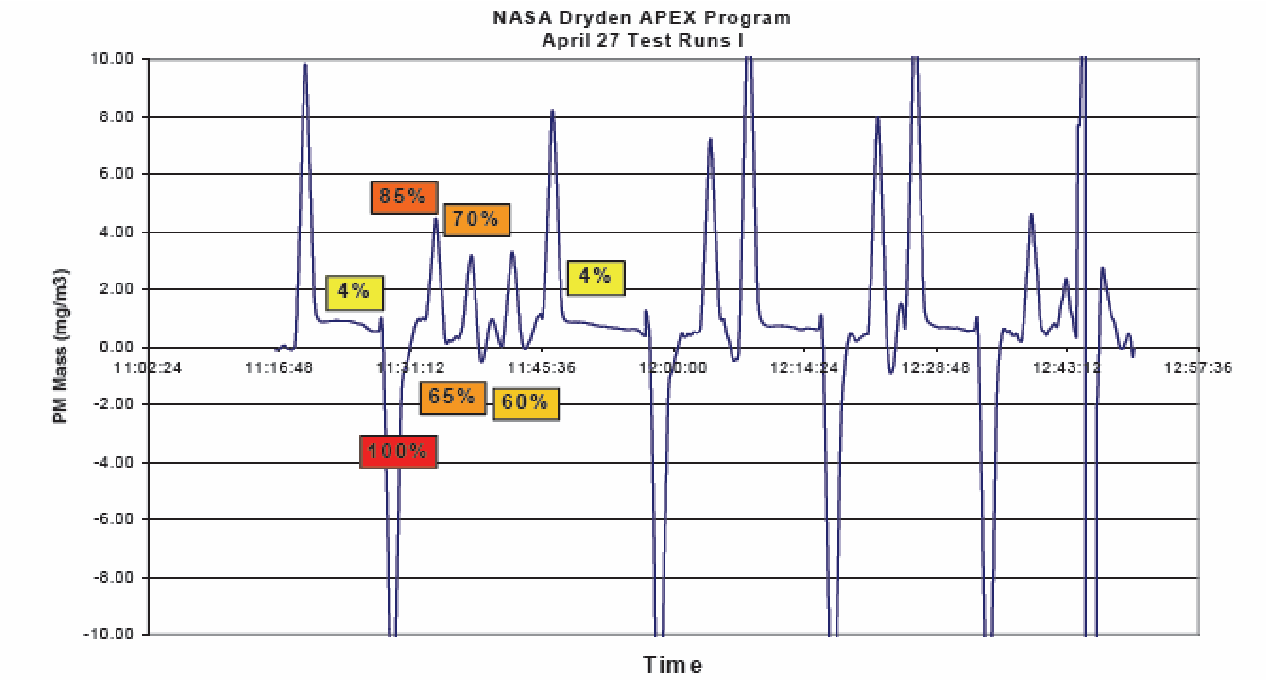
Hagen et al., 2006, "Volatile Aerosol in Gas Turbine Emissions", Proc. 10th-Combustion Generated Nanoparticles Conf., Zurich, Switzerland

Direct Mass Measurements

- Good understanding of size, number and shape
- Need a direct mass measurement
- Effective density of jet engine exhaust particles
- Previous work with TEOM, DMM

Data from TOEM

Corporan et al., 2004, "CFM56 Engine PM Mass Measurements using a TEOM",
APEX Conference, Cleveland OH, November 2004



Engine Condition	Mass (mg/m3)	Error
4%	0.869	9%
4%	0.711	20%
4%	0.665	14%
4%	0.628	14%

- Large data scatter at high power due to high vibration
- Takes relatively long (4-5 mins) to stabilize after change in engine condition

Lab Experiments

Goal:

To examine the performance of a Cambustion DMS500 – DMM combination to determine the effective density of diesel exhaust particles

Cambustion DMS500

Dekati Mass Monitor (DMM) is a real-time instrument for automotive particulate mass emission measurements

Dekati Mass Monitor (DMM)

Moisio, M. Niemelä, V. “Device for Continuous Measurement of Density and Mass Concentration of Vehicle Exhaust Aerosol”, IAC 2002.

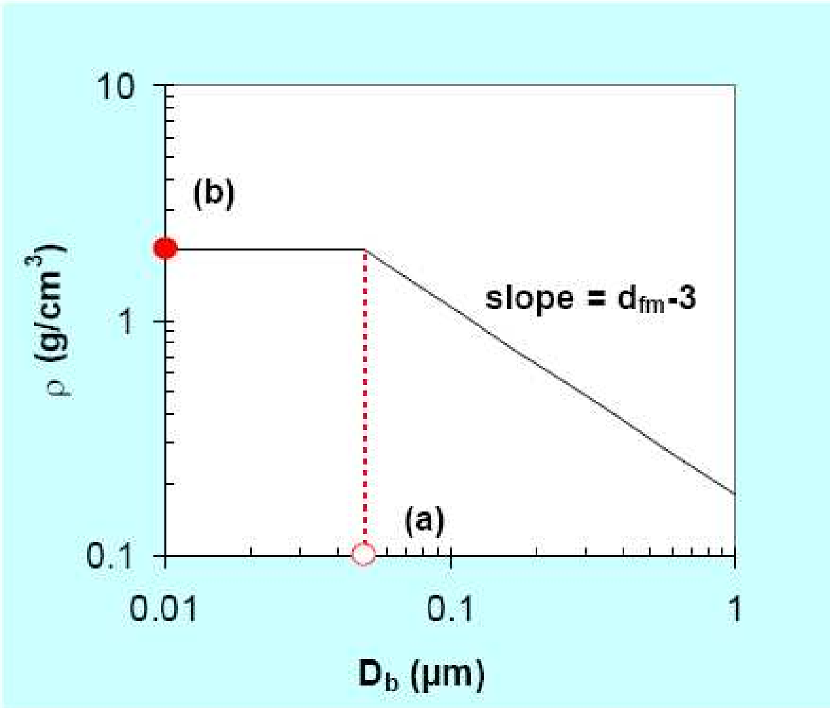
DMM gives mass concentration

DMS500 gives number concentration which can be converted into a volume concentration

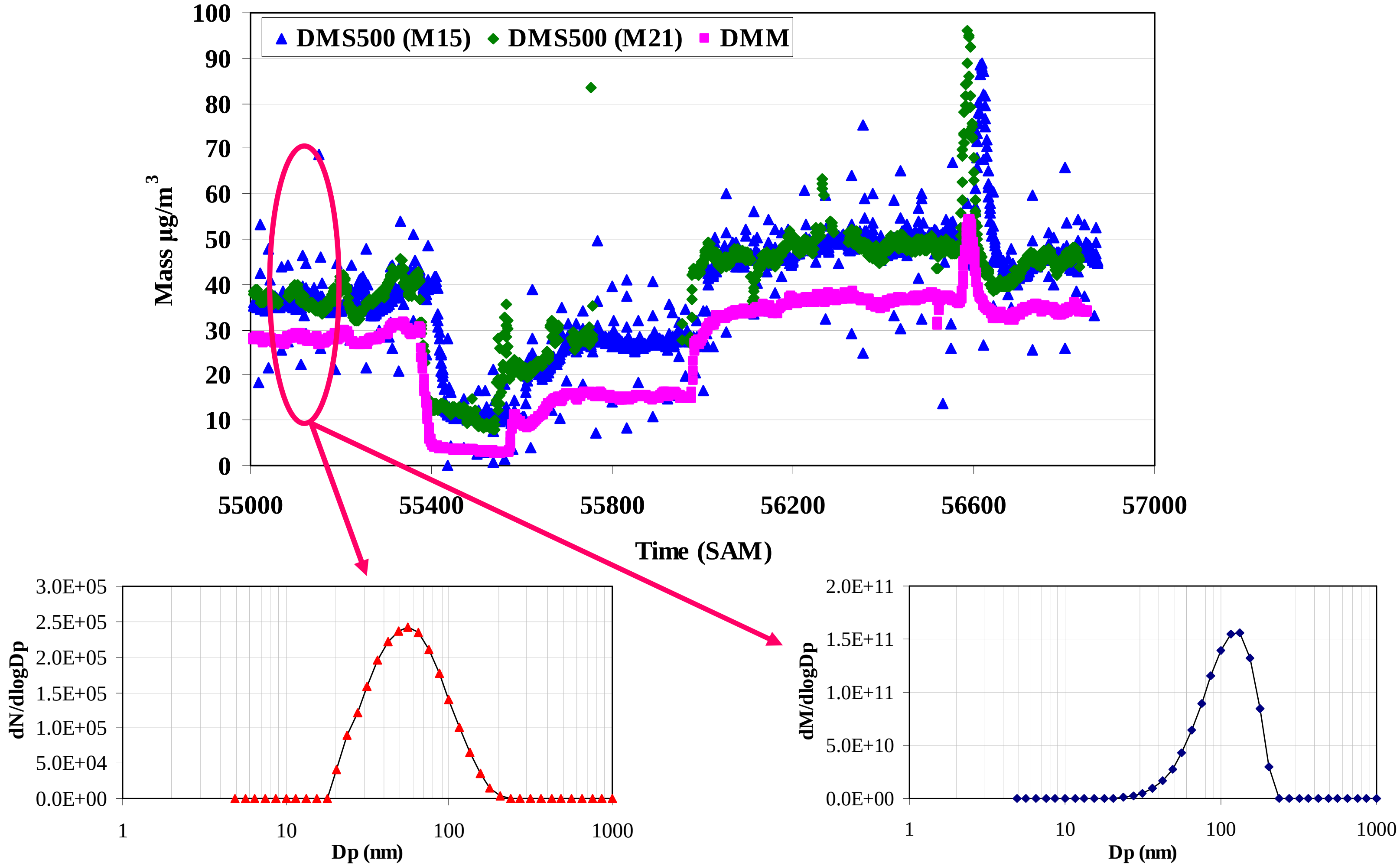
The ratio of DMM mass conc. to DMS500 volume conc. gives the effective density of the particles

Density as function of particle size: Diesel Agglomerates

Virtanen et al SAE 2002-01-0056



Concentration Profile and Size Distributions



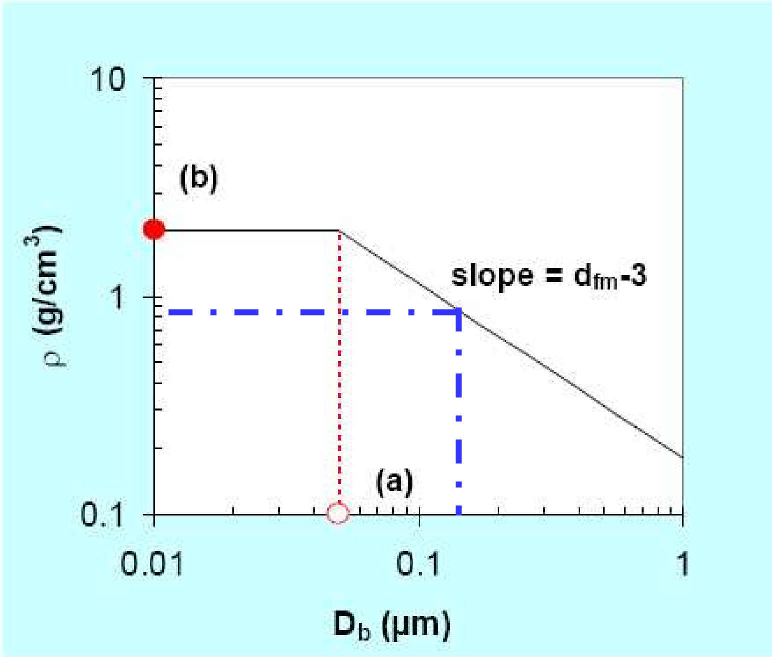
Effective Density

- Effective density

$$= \frac{\text{DMM mass conc}}{\text{DMS500 volume conc}}$$

$= 0.8 \pm 0.1$ g/cc

Virtanen et al SAE 2002-01-0056



NASA Glenn Sampling Study – November 2006

Cambustion DMS500

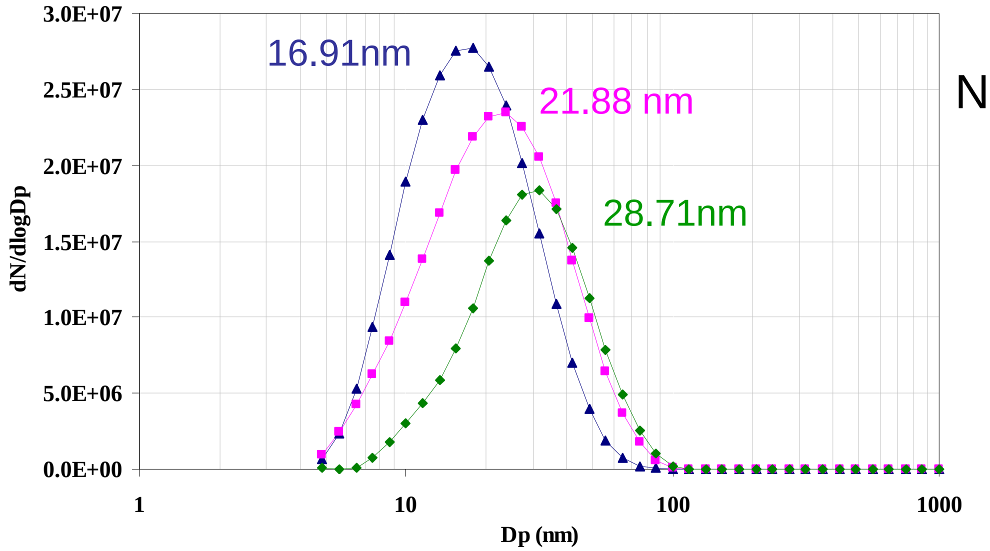
Dekati Mass Monitor (DMM)

Change in DMM set points for application to jet engine exhaust

- Fractal dimension changed from 2.5 to 3

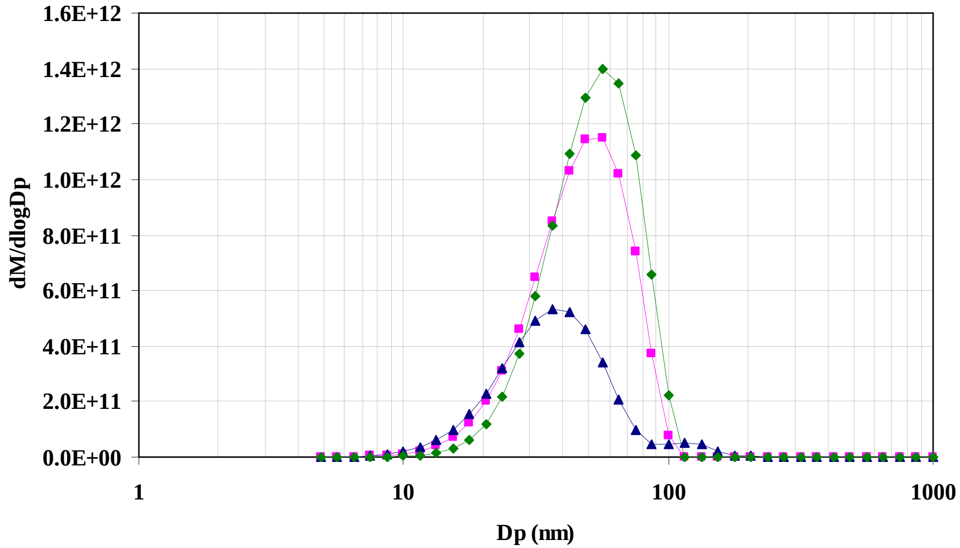
Schmid et al., 2004 “Methodology for Particle Characterization in the Exhaust Flows of Gas Turbine Engines”, *Aerosol Sci. Technol.*

Size Distributions



Number-based size distribution

Mass-based size distribution

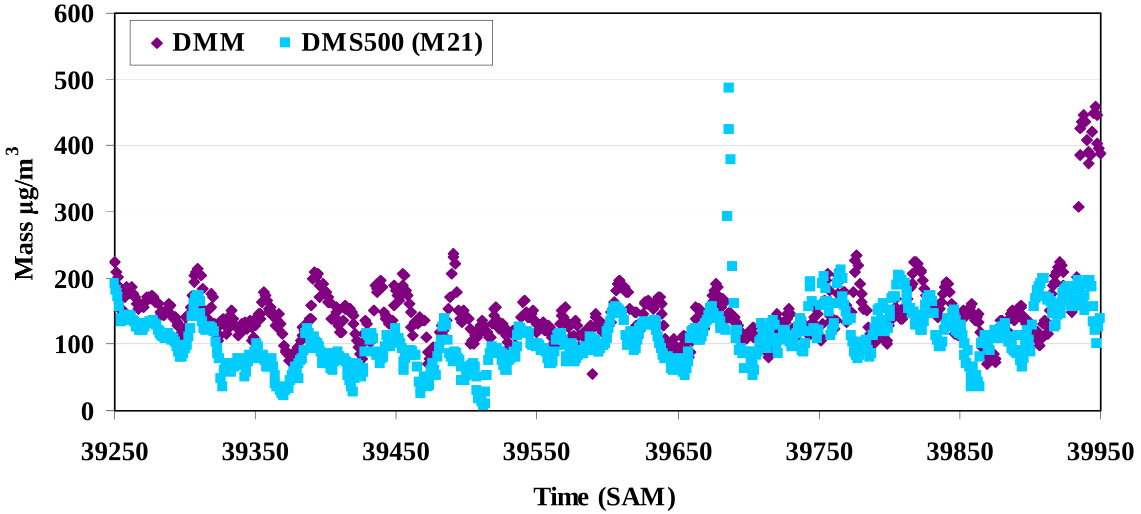


Concentration Profiles

Engine power setting = idle

Mean particle size = 18.6 nm

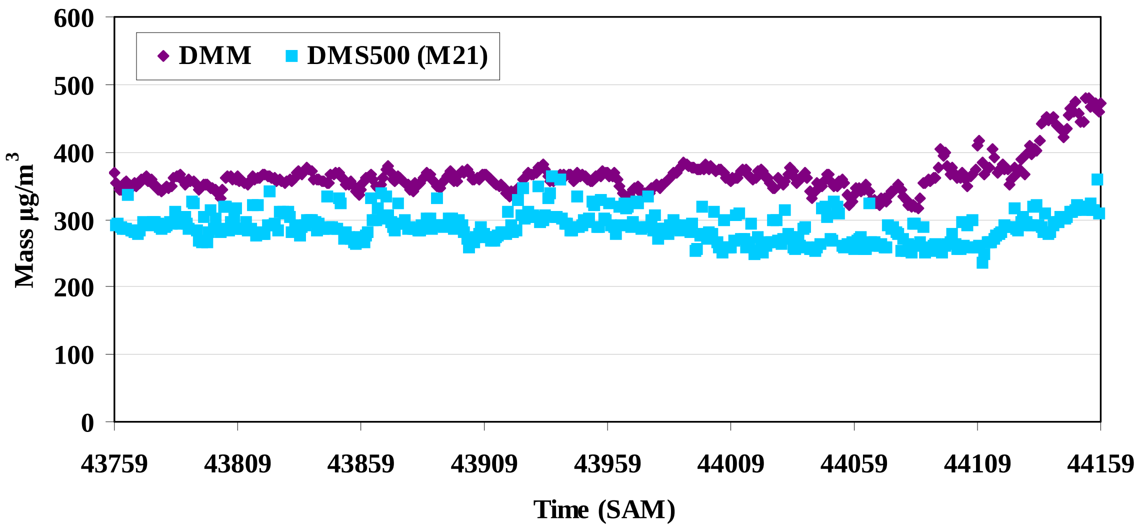
Density = 1.34 g/cc



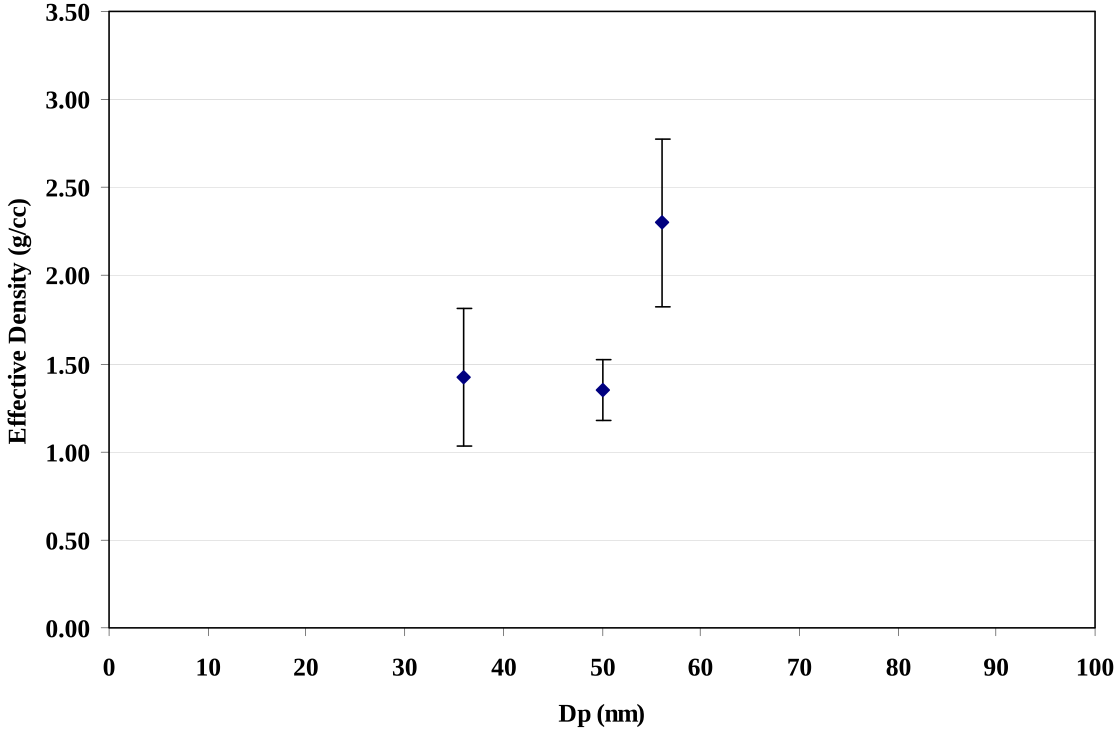
Engine power setting = 30%

Mean particle size = 21 nm

Density = 1.47 g/cc



Density vs. Particle Size



Conclusions/Future Work

- DMS500-DMM technique to determine effective density
- Jet engine exhaust particle density
- More data acquired at a recent test involving a military engine

Acknowledgements

PARTNER

Partnership for AiR Transportation Noise and Emission Reduction

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California Air Resources Board

United States Environmental Protection Agency

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