Aerosol Sampling Issues and System Design

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APEX Particle Measurement Objectives

• Characterize particle size, number, mass and composition as a function of engine power

• Examine spatial variation of across exhaust plane

• Monitor changes in particle concentrations and properties as plume dilutes and cools

• Evaluate new instruments and sampling techniques
Processes Influencing Particle Size and Concentration

- Inertial Effects
- Thermophoretic Effects
- Loss in Bends
- Turbulent Deposition
- Gravitational Settling
- Coagulation
Sampling System Design Challenges

Coagulation for EI=5e15/kg

15 m pipe @ 10 LPM

Initial

2 Seconds Later

Nf/No=0.28

Diameter (nm)
Effects of Non-isokinetic Sampling

Velocity Ratios (m/s) Exhaust/Inlet

Fractional Penetration

Diameter (nm)
Sampling System Design Challenges

Relative Humidity of Sample
100 % Power Setting

![Graph showing relative humidity as a function of sample temperature for different dilution ratios: 2:1, 4:1, 8:1, and no dilution.](image)
Sampling System Design Criteria

- Perform dilutions close to inlet tip
- Draw samples isokinetically if possible
- Include multiple inlet tips at 1 m to allow exhaust profiling
- Include secondary inlets at 10 and 30 m to facilitate aging study
- Include automated valving system to speed up sample selection
- Provide 50 LPM total flow with low pressure drop across system
- Minimize bends, connections, line lengths, and sample residence times
APEX Experimental Setup

DC-8

1 m Rake, 6 ports
10 m Rake, 6 ports
30m Probe, 1 port

EPA Trailer will house LaRC equip. and valving system

2 lines, one dedicated to EPA unheated, no dilution

3/4”
APEX Aerosol Sampling System

- 1 m Rake: 0.29” x 1.8 m
  - Valve Box: 0.19” x 1.5 m
  - 0.62” x 23.8 m

- 10 m Rake: 0.29” x 1.8 m
  - Valve Box: 0.19” x 1.5 m
  - 0.62” x 20.7 m

- 30 m probe: 1.9” x 29.3 m
  - EPA Trailer: 0.62” x 23.8 m
  - 0.62” x 20.7 m
AEDC Aerosol Sample Inlet

- Green = Sample
- Light Purple = Water
- Yellow = Diluent

Section A-A
1 and 10 m Aerosol Rake Systems

6 – Port Sample Rake

- HEPA
- Dilution Gas (Dry N2)
- 3/8” S.S. Tubing
- Zero Gas Line

Converging Manifold

- 3/8” I.D. Ball Valves Pneumatically Actuated
- 3/8” S.S. Tubing
- Aerosol Sample To EPA Trailer

- 3/4” S.S. Tubing
- 1/4” S.S. Tubing
- 3/8” S.S. Tubing
- 1/4” to 3/8
Aerosol Sample Valve Boxes
Aerosol Sample Distribution System
### Sample System Flow Characteristics

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<th>Sampling System</th>
<th>Flow Parameters</th>
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<th>10 m Probe</th>
<th>30 m Probe</th>
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</table>
Sample System Flow Characteristics

Diffusional and Inertial Particle Losses

Fractional Penetration vs. Particle Diameter (nm)

- 30 Probe
- 1 and 10 m Rakes

Sample System Flow Characteristics

Sample System Flow Characteristics
Relative Sampling Efficiency of Inlets

Baseline Fuel

Nonvolatile CN EI (#/kg) vs. Sampling Distance (m)

- 100%
- 85%
- 65%

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Relative Sampling Efficiency of Inlets

Hi Sulfur Fuel

Nonvolatile CN El (#/kg) vs. Sampling Distance (m)

- 100%
- 85%
- 65%

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Impact of Dilution upon Aerosol Samples

Impact of Dilution on EI

Sample CO2
- 3200 ppm
- 1600 ppm
- 800 ppm

Engine Power

Sample CO2
- 3200 ppm
- 1600 ppm
- 800 ppm

(X 1.E15)
Impact of Dilution upon Aerosol Samples

DC-8 Plume Dilution

Dilution Ratio vs. Engine Power (%)

- 30 meters
- 10 meters
Impact of Dilution upon Aerosol Samples

Aerosol Sample Dilution at 1 m

Dilution Ratio

Engine Power (%)
Impact of Dilution upon Aerosol Samples

40% Power, 1 m Rake

CN Emission Index (#/kg)

Dilution Ratio

Total

Nonvolatile

1E14

1E15
Impact of Dilution upon Aerosol Samples

40% Power, 1 m Rake

CN Emission Index (#/kg) vs. Dilution Ratio

- Nonvolatile
- Total
Impact of Dilution upon Aerosol Samples

![Graph showing the relationship between CN Emission Index (#/kg) and Dilution Ratio for 40% Power, 10 m Rake. The graph displays two categories: Total and Nonvolatile. The x-axis represents the dilution ratio ranging from 0.5 to 4.5, and the y-axis represents the CN Emission Index from 6.00E+013 to 1.60E+014.]
Impact of Inlet Probe upon Sample Integrity

CFM-56 Emissions

Engine Power (%) vs. Particle EI (#/kg)

- Hi Aromatic Fuel
- 1 m Aerosol Probe
- 1 m Gas Probe

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Impact of Inlet Probe upon Sample Integrity

CFM-56 Emissions

Black Carbon EI (mg/kg) vs Engine Power (%)

Hi Aromatic Fuel

1 m Aerosol Rake

1 m Gas Rake

1 m Gas Rake

1 m Aerosol Rake
Summary

• Multi-port aerosol sampling system was designed, built, and successfully deployed during APEX

• Experiments suggest that sample dilutions were adequate to prevent both coagulation losses and formation of new particles within sample lines

• Comparison of data from 1 and 10 m probes indicate that thermophoretic and inertial losses are not a significant problem

• Comparison of data from “aerosol” and “gas” sample inlets suggest that standard gas sampling tips/lines perturb aerosol samples, reducing both numbers and mass