Aircraft Particle Emissions eXperiment (APEX)

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

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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%)
Sampling Probe Stand

CFM56-2 ENGINE

NASA GRC Emissions Rake

UMR Rake Stand

All dimensions in inches
Sampling Probe Configuration

All dimensions in inches

<table>
<thead>
<tr>
<th>G</th>
<th>P</th>
<th>Gas Emission</th>
<th>Particulate</th>
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CFM56-2 ENGINE

Flow

~ 4” diameter

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

1" OD Tubing

1.0

4 x 0.5 thru holes

5.0

13.0

Cover

1.25

1.25 Typ.

13.75

19.25

4.25

In

Water

Out

Not Used
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

The graph shows the percentage of engine power over time from 09:00:00 to 17:00:00 on 4/23/2004. The data indicates that the aircraft moved 3.5 inches during the observed period.
NASA High Sulfur Fuel Sequence #1

4/27/2004

Engine Power, %

0 20 40 60 80 100

Time

15:00:00 15:30:00 16:00:00 16:30:00 17:00:00

NASA Base Fuel Sequence #1 & #2 High Power conditions

4/27/2004

Time

08:00:00 08:30:00 09:00:00 09:30:00 10:00:00

Engine Power, %

0 20 40 60 80 100

NASA High Sulfur Fuel Sequence #1

4/27/2004

Engine Power, %

0 20 40 60 80 100

Time

15:00:00 15:30:00 16:00:00 16:30:00 17:00:00
Measurements Performed

Aerodyne Research, Inc.
- NO, NO₂, HONO, H₂CO, C₂H₂, CO, N₂O, CO₂
- Non-refractory aerosol size, selected number density, and composition
- Various Oxy-VOC and aromatics

Arnold Engineering Development Center
- CH₄, HCHO, C₂H₄, CH₃OH, COOH, SO₂, H₂O, CO, CO₂, N₂O, NO, NOₓ
  possible C₂H₆, C₄H₆, C₂H₂, CH₃CHO, C₇H₈
- Smoke Number
- Non-volatile mass
- Total temperature

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, CO₂, 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, CO₂, O₂, NO, NOₓ, UHC
• CH₄, HCHO, C₂H₄, CH₃OH, COOH, SO₂, H₂O, CO, CO₂, N₂O, NO, NOₓ
  possible C₂H₆, C₄H₆, C₂H₂, CH₃CHO, C₇H₈

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
• CO₂
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$_2$, 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?