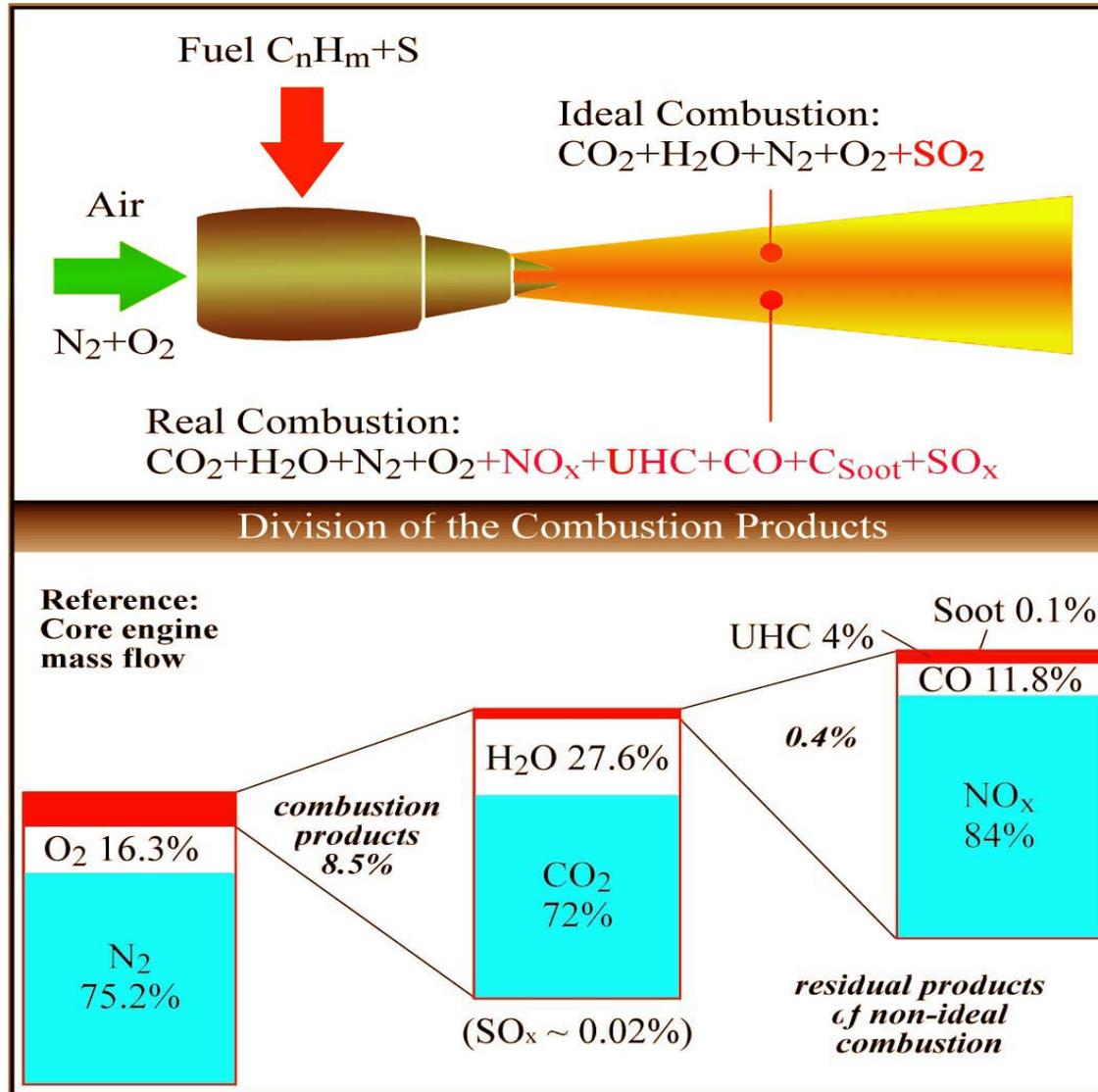


# **Aviation Particulate Emissions Research**

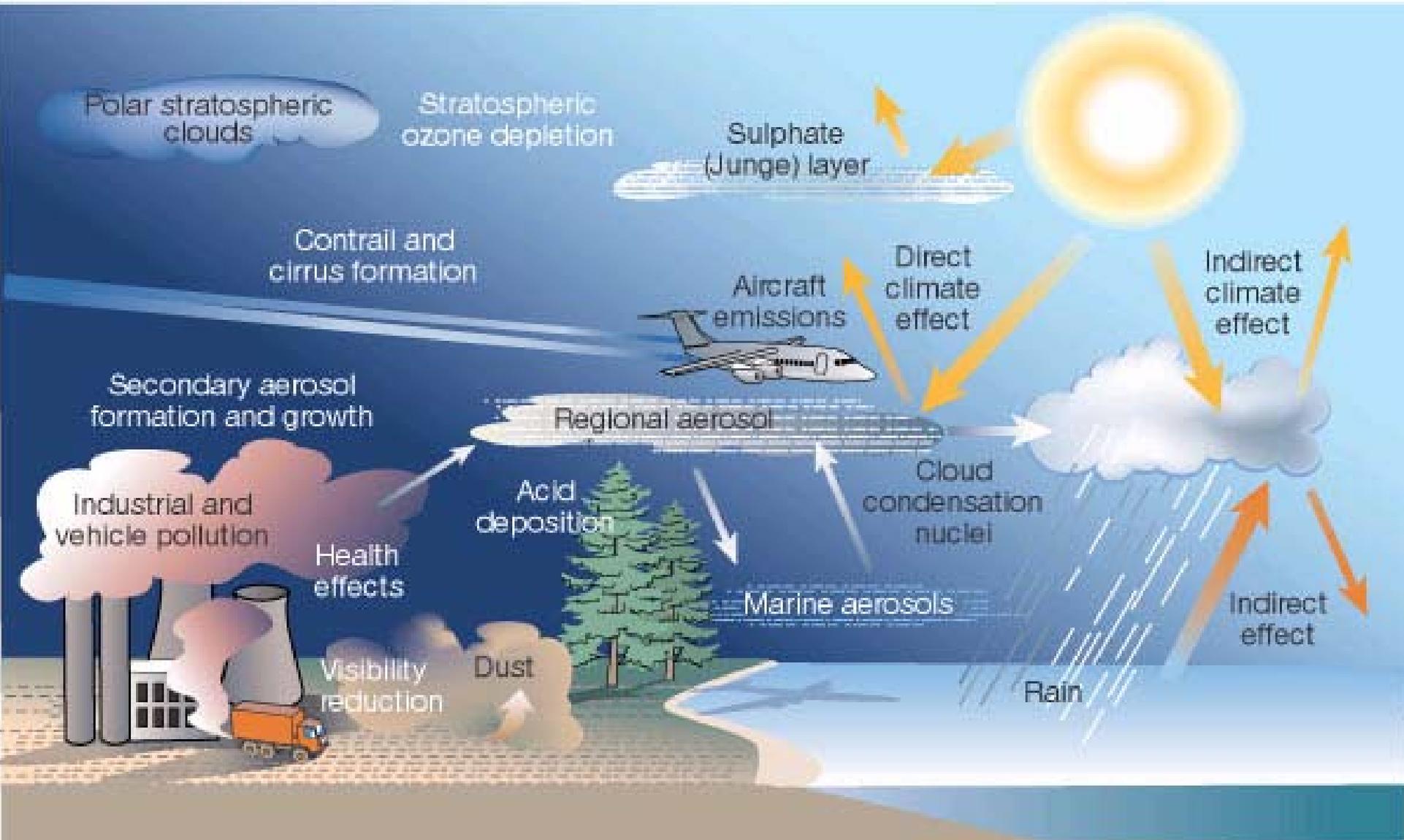
**Dr. Chowen Chou Wey  
ARL/NASA GRC  
chowen.c.vey@grc.nasa.gov**

**CARB  
August 22, 2005**

# Aircraft Engine Emissions



# Aerosols in the Atmosphere



# Environmental Issues - Particles (1)

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## Global Climate Change

- **Direct radiative impact of particles (small)**
- **Aerosol loading for heterogeneous chemistry (small)**
- **Impact due to cloud formation**
  - **Contrails**
    - **immediate impact due to linear clouds**
    - **evolve into aircraft-generated cirrus**
  - **Formation of cirrus due to deposition of condensation nuclei (clouds form later on emitted particles?)**

# Environmental Issues - Particles (2)

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## Local Air Quality

- **Human health: respirable particles**
  - **Particle deposition in lungs**
  - **Delivery of compounds in particles, on surface**
- **Condensation nuclei for smog and haze**
  - **Interaction with chemical species in airshed**
  - **Surface area for heterogeneous chemistry**
  - **Visibility impairment, soiling due to deposition**

# Current Particle Measurement Standard

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- **Smoke Number, regulatory metric for aircraft engine particle emissions, does not directly address particle parameters responsible for health effects and environmental impacts**
- **Existing EPA Method 5 for PM measurement designed in 1950's for smoke stake, inappropriate for characterization of aircraft engine particle emissions**

# Requests to SAE E-31 Committee

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- **International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) asked E-31 for technical assistance in developing appropriate particulate characterization techniques for routine certification of aircraft turbine engines**
- **US EPA and FAA encouraged E-31 to provide technical guidance**
- **US DoD collaborate with E-31**

# DoD Concerns – PM Measurement

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- **Requirements to military base:**
  - **Currently required to provide PM<sub>10</sub> data (mass based) for NAAQS**
  - **Anticipate similar requirement on PM<sub>2.5</sub> data**
- **Near term focus: find an alternate approach to measure PM mass by collaborating with**
  - **EPA**
  - **SAE E-31**
  - **NASA**
  - **FAA**

# SAE E-31 Committee

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**Society of Automotive Engineers (SAE)  
E-31 Committee chartered in 1968  
“to establish standard methods and  
instrumentation for all types of  
exhaust emissions, other than normal  
atmospheric constituents, from  
aircraft engines ...”**

# Particle Emissions Types

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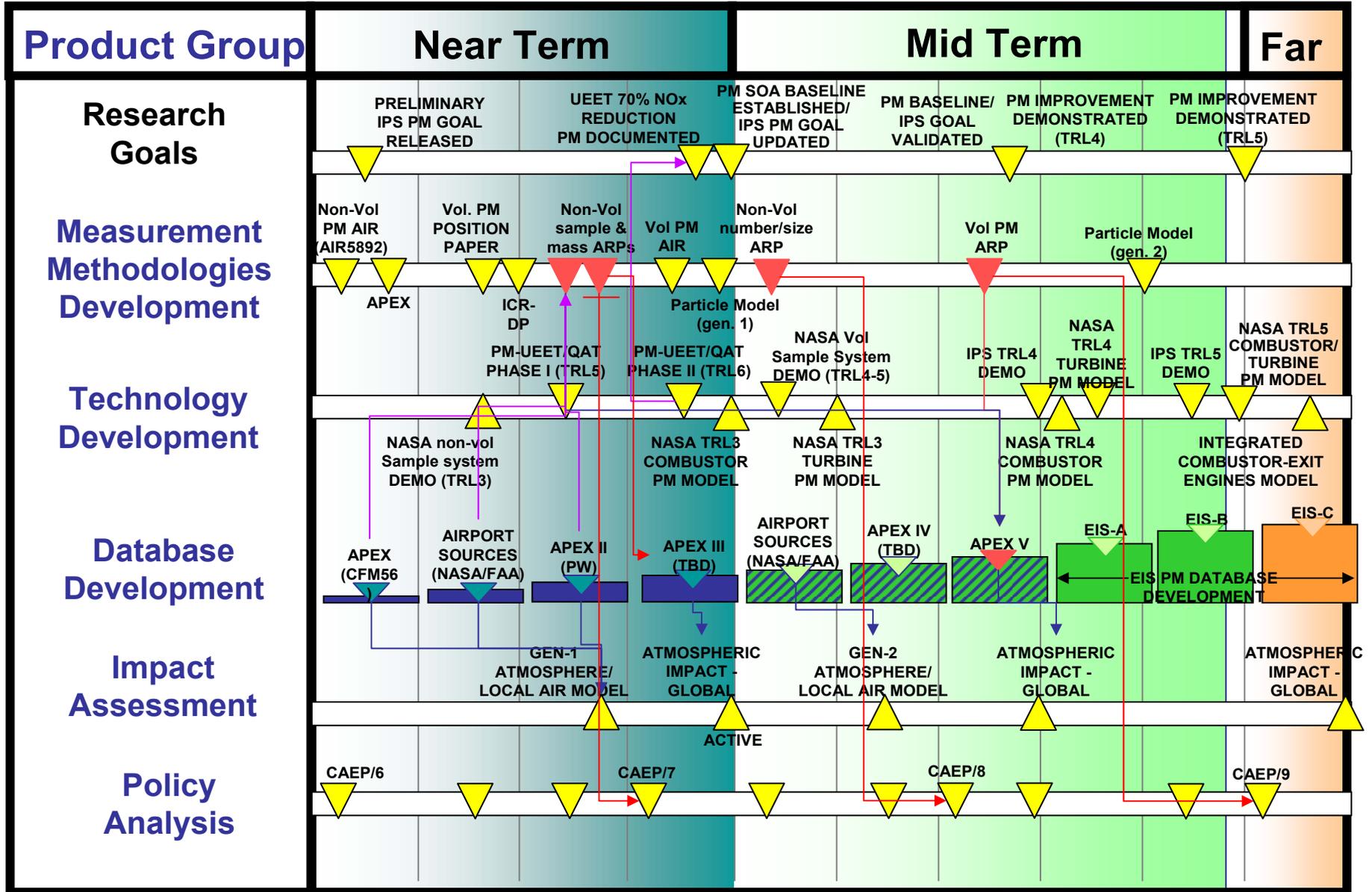
- **Those formed by combustion processes within engine (non-volatile)**
    - **small carbonaceous particles**
  - **Those formed by condensation of gases after exhaust leaves engine (volatile)**
    - **sulfur species**
    - **unburned and partially oxidized fuel, engine lubrication oil**
- ❖ **pure volatile particles versus coated soot**

# SAE E-31 Committee – Approach & Status

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- **Two paths to standardize particle measurement methodology for aircraft engine emissions**
  
- **non-volatile**
  - **Position Paper and Aerospace Information Report (AIR 5892) published**
  - **3 Aerospace Recommended Practice (ARP) being worked separately for sampling, mass, number/size**
  
- **Volatile**
  - **Position Paper final draft being reviewed**

# PM National Roadmap – Draft Example



# PM National Roadmap – 5 Groups

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## ➤ Policy Analysis

- **Curtis Holsclaw/FAA**

## ➤ Measurement & Methodology Development

- **Chowen Wey/NASA & Rick Miake-Lye/ARI**

## ➤ Impacts Analysis

- **Ian Waitz/MIT & Malcolm Ko/NASA**

## ➤ Technology Development

- **Chi-Ming Lee/NASA & William Sowa/P&W**

## ➤ Database Development

- **Philip Whitefield/UMR & Carl Ma/FAA**

# PM National Roadmap – Status

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## ➤ Stakeholder meeting

- 1<sup>st</sup>: January 13, 2004
- 2<sup>nd</sup>: October 6, 2004
- 3<sup>rd</sup>: May 19, 2005

## ➤ Teleconferences

## ➤ Final draft document in a month(?)

## ➤ Annual stakeholder meeting

# NASA Emissions Reduction Research

**8-15% fuel burn reduction - Reduction of CO<sub>2</sub> & H<sub>2</sub>O emissions**

high-fidelity system studies

highly loaded turbomachinery

long-life, high temperature, light-weight material

propulsion/airframe integration

CO<sub>2</sub>

H<sub>2</sub>O

**70% NO<sub>x</sub> reduction - Less impacts on O<sub>3</sub> & CH<sub>4</sub> chemistry**

low-NO<sub>x</sub> combustion concepts

advanced liner design with high-temperature material

O<sub>3</sub>

CH<sub>4</sub>

**Emissions characterization - understanding particulate emissions**

sampling system

measurement system

emissions measurements – combustor, engine, aircraft

kinetics of particulate & its precursors

modeling – combustor, turbine hot section, plume/wake

database, inventory, scenario

Sulfate & Soot  
Aerosols

Contrails

Cirrus Clouds

**Atmospheric modeling - understanding atmospheric impact**

global modeling - GMI

# Particulate Emissions Research

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## **Emissions characterization - understanding particulate emissions**

- **sampling system**
- **measurement system**
- **emissions measurements – combustor, engine, aircraft**
- **kinetics of particulate & its precursors**
- **modeling – combustor, turbine hot section, plume/wake**
- **database, inventory, scenario**

# Measurements: Combustion Test Rigs (1)

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## NASA simulated altitude engine tests

- **Engine (AEDC TR-96-3)**
  - **1995 at AEDC**
  - **Measurement team: AEDC, ARI, UMR**
- **F100 Engine (NASA TM 1998 208509)**
  - **1997 at NASA GRC**
  - **Measurement team: ARI, AFRL, NASA, UMR, UTRC**

## NASA-QinetiQ collaboration

- **Combustor rig (NASA CR 2002-211899)**
  - **2000 at DERA**
  - **Measurement team: ARI, DERA, UMR**
- **Engine (NASA CR 2002-211900)**
  - **2001 at QinetiQ**
  - **Measurement team: ARI, QinetiQ, UMR**

# Measurements: Combustion Test Rigs (2)

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## DoD collaboration

### ➤ T63 Engine

- 2001 at WPAFB
- Measurement team: NASA, WPAFB

### ➤ T700 Engine

- 2003 at Navy Pax River
- Measurement team: NASA

## Industry collaboration

### ➤ Annular Combustor

- 2004/2005 at PW
- Measurement team: ARI, NASA, PW, UTRC

## NASA combustor rigs

# Measurements: Aircraft on Ground

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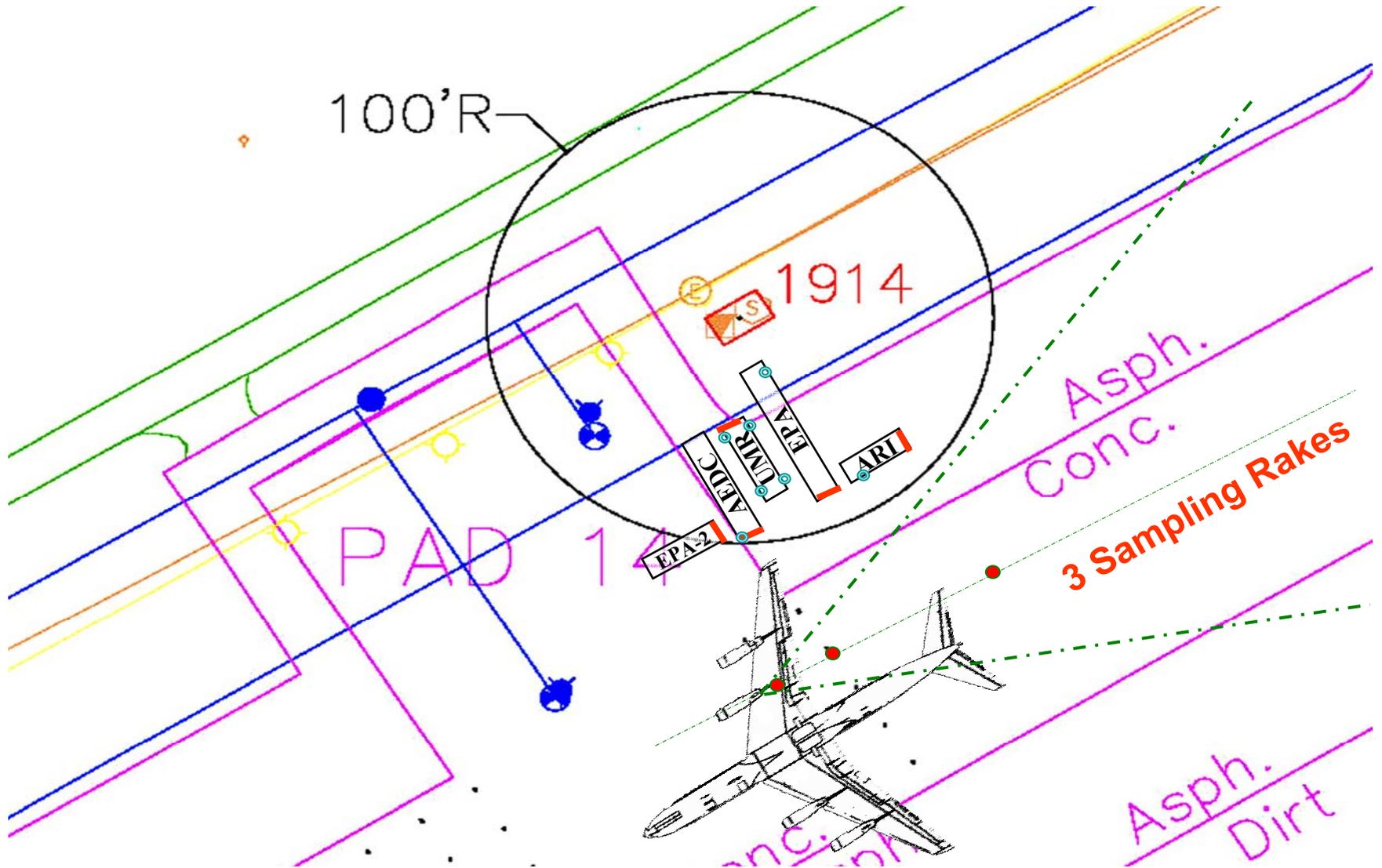
## Experiment to Characterize Aircraft Volatile Aerosol and Trace Species Emissions (EXCAVATE)

- **2002 at NASA LaRC**
- **B757 aircraft with RB211 engine**
- **Measurement team: ARI, NASA**

## Aircraft particle Emissions eXperiment (APEX)

- **2004 at NASA DFRC**
- **DC8 aircraft with CFM56 engine**
- **Measurement team: ARI, DoD (AEDC, AFRL, PM, UCR), EPA, NASA, UMR**

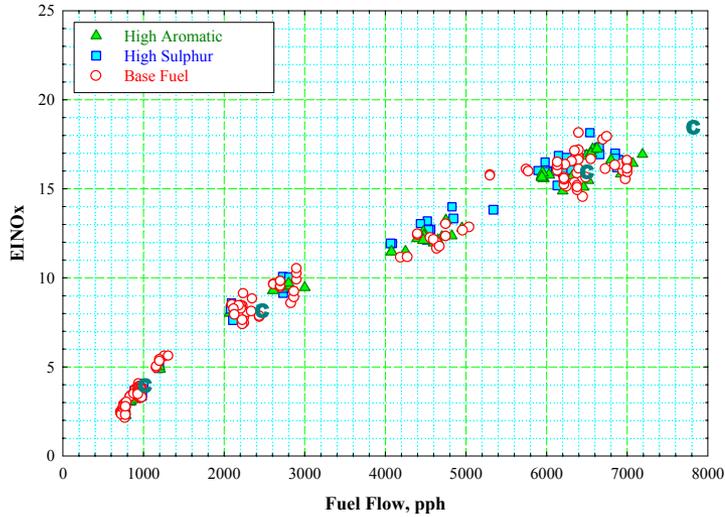
# APEX



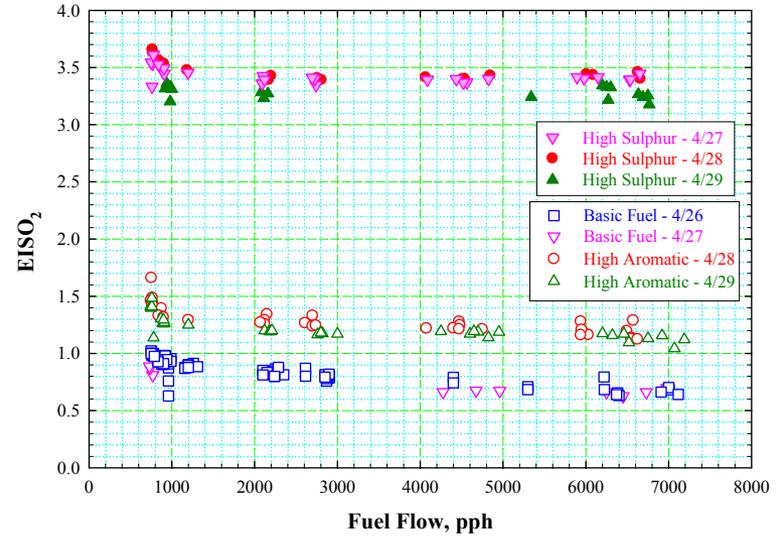


# APEX Gaseous Data Example

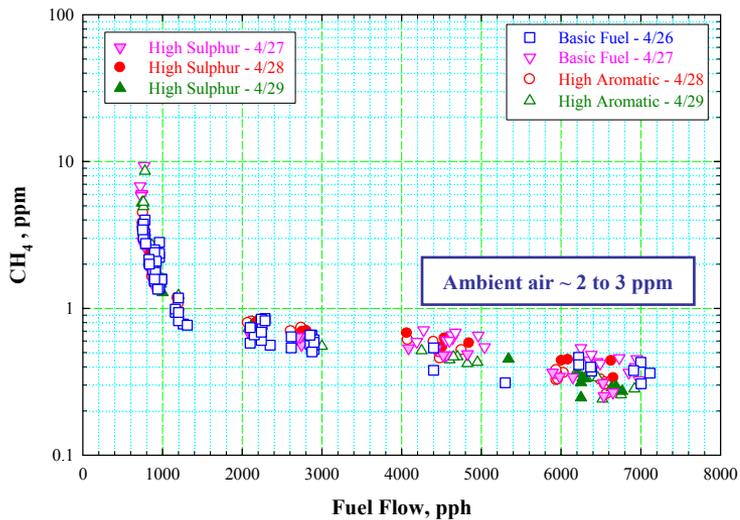
## $EINO_x$



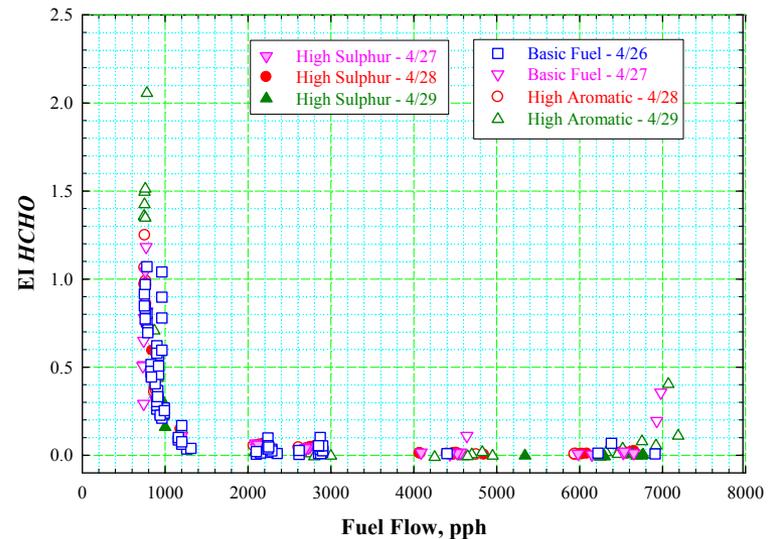
## $EISO_2$



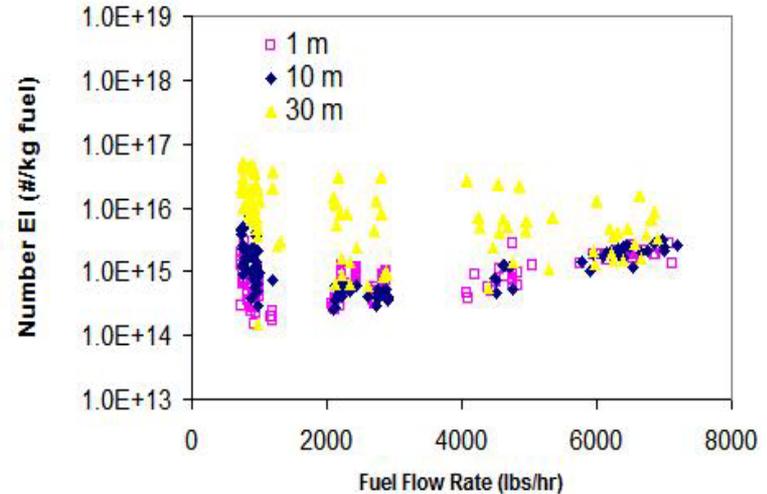
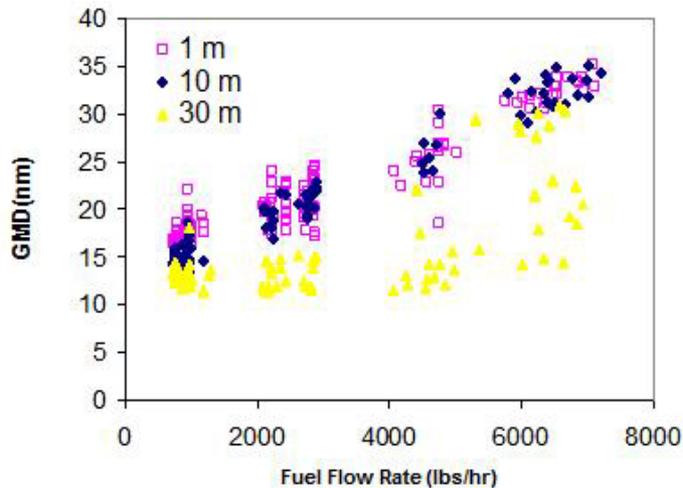
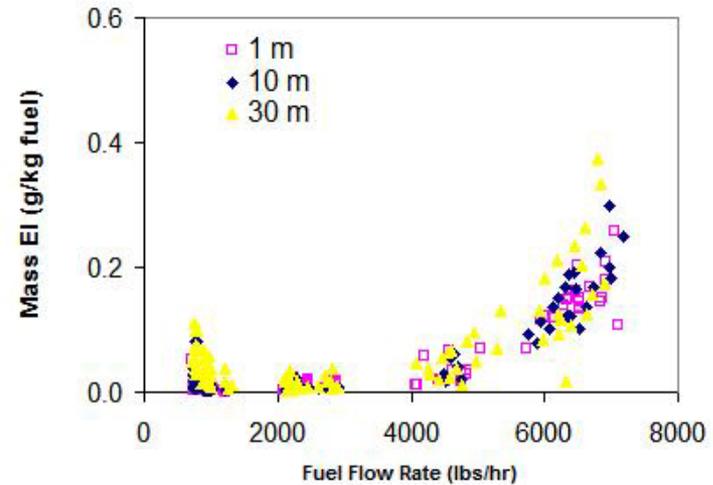
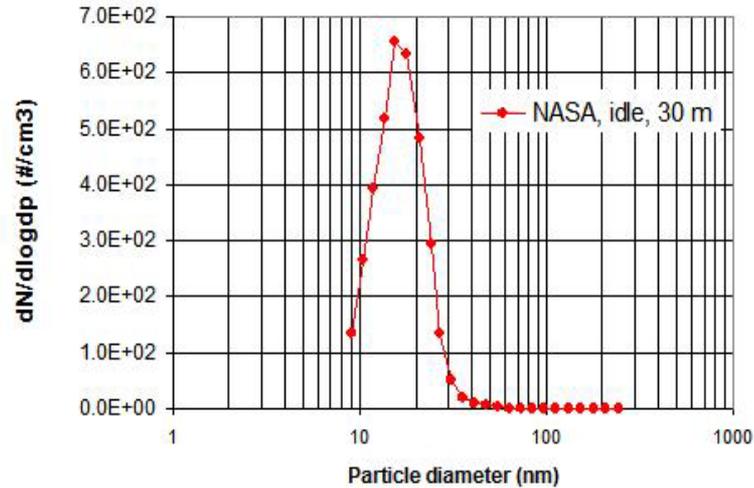
## $CH_4$



## $EIHCHO$



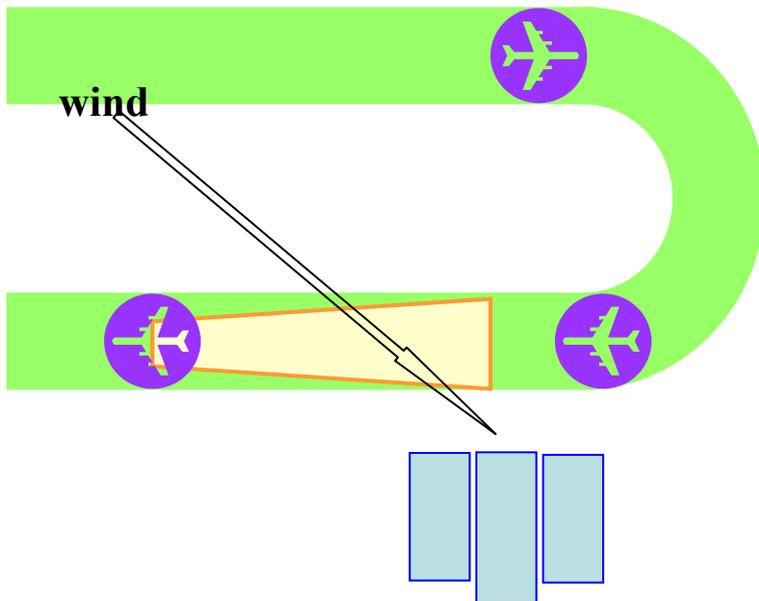
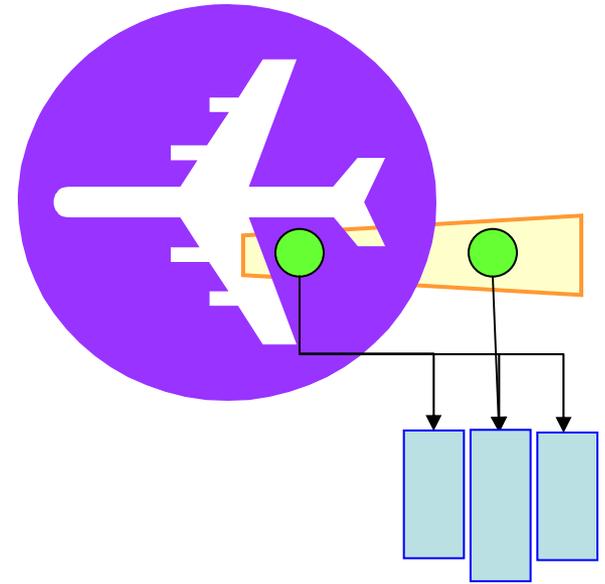
# APEX Particulate Data Example



# Measurements: Airline/Airport

## Airline Study: static parametric study

- ✓ Exhaust characterization
- ✓ Plume evolution



## Airport Study: dynamic dispersion study

- ✓ Taxi
- ✓ Take-Off

# Measurements: Airline/Airport (1)

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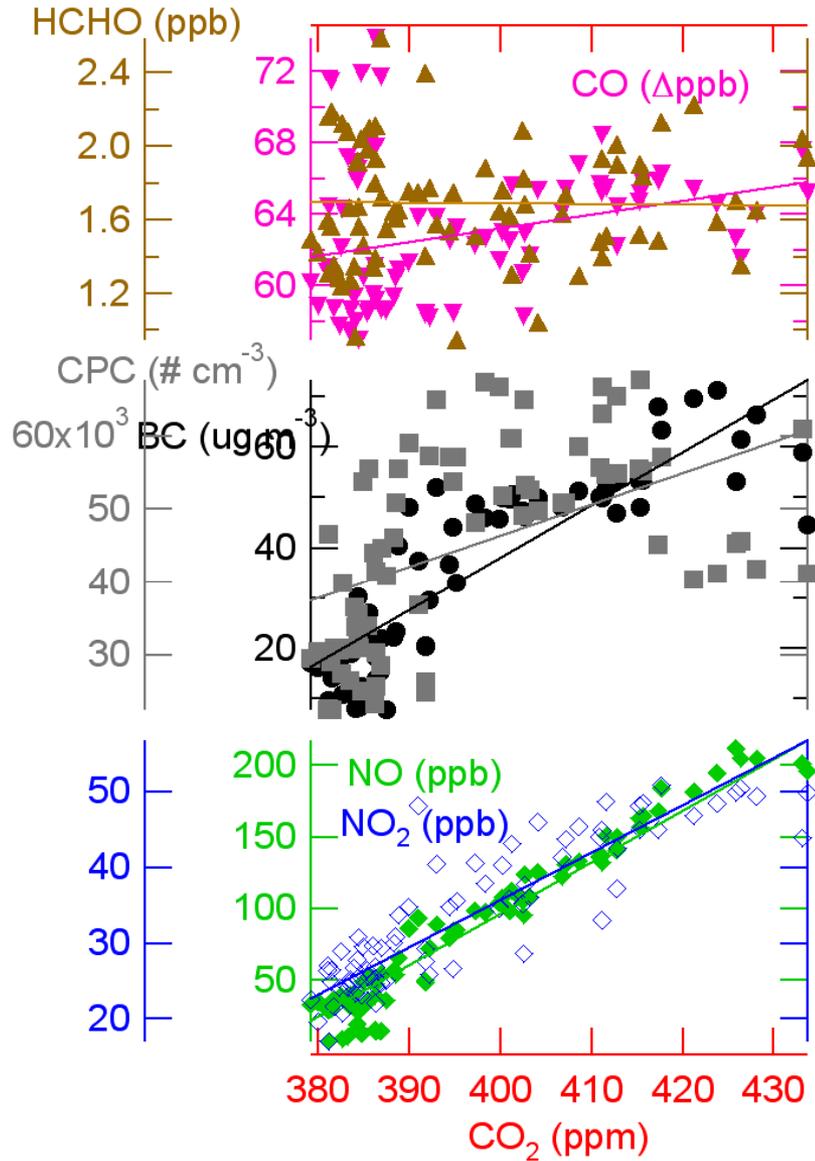
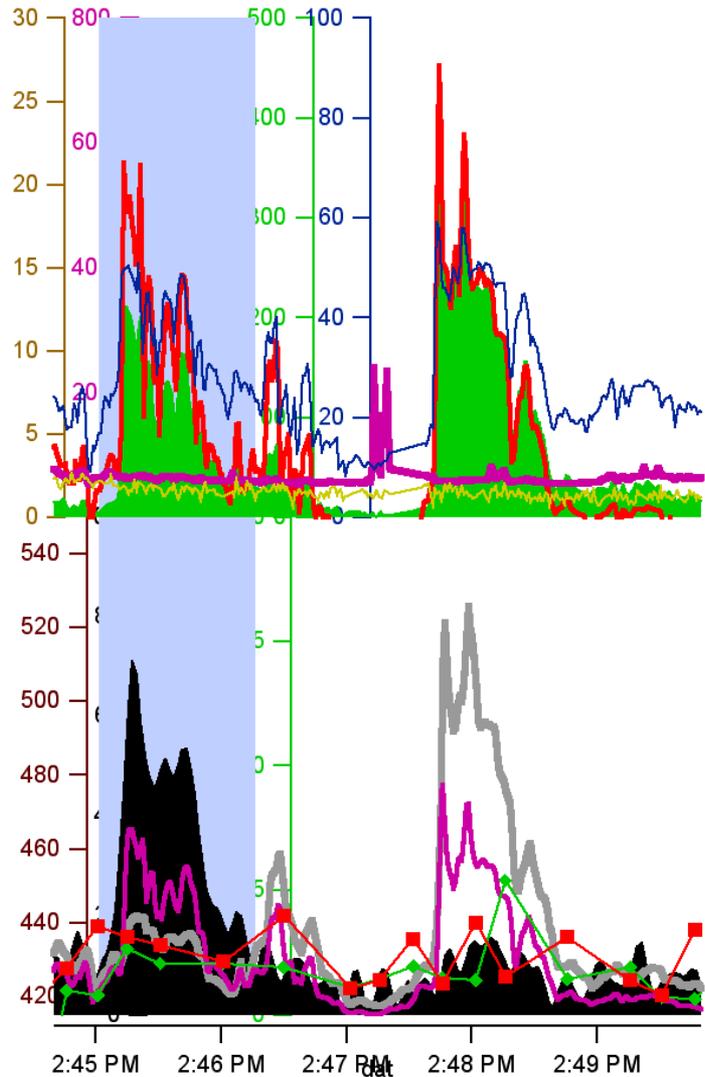
## Un-Named Airline Un-Named Airport (UNAUNA)

- **2004 with a major airline at a major airport**
- **Aircraft/engine combination**
  - **MD88 with JT8D engine**
  - **B757-200 with PW2037 engine**
  - **B767-300/400 with CF6 engine**
- **Measurement team**
  - **ARI**
  - **NOAA**
  - **UMR**

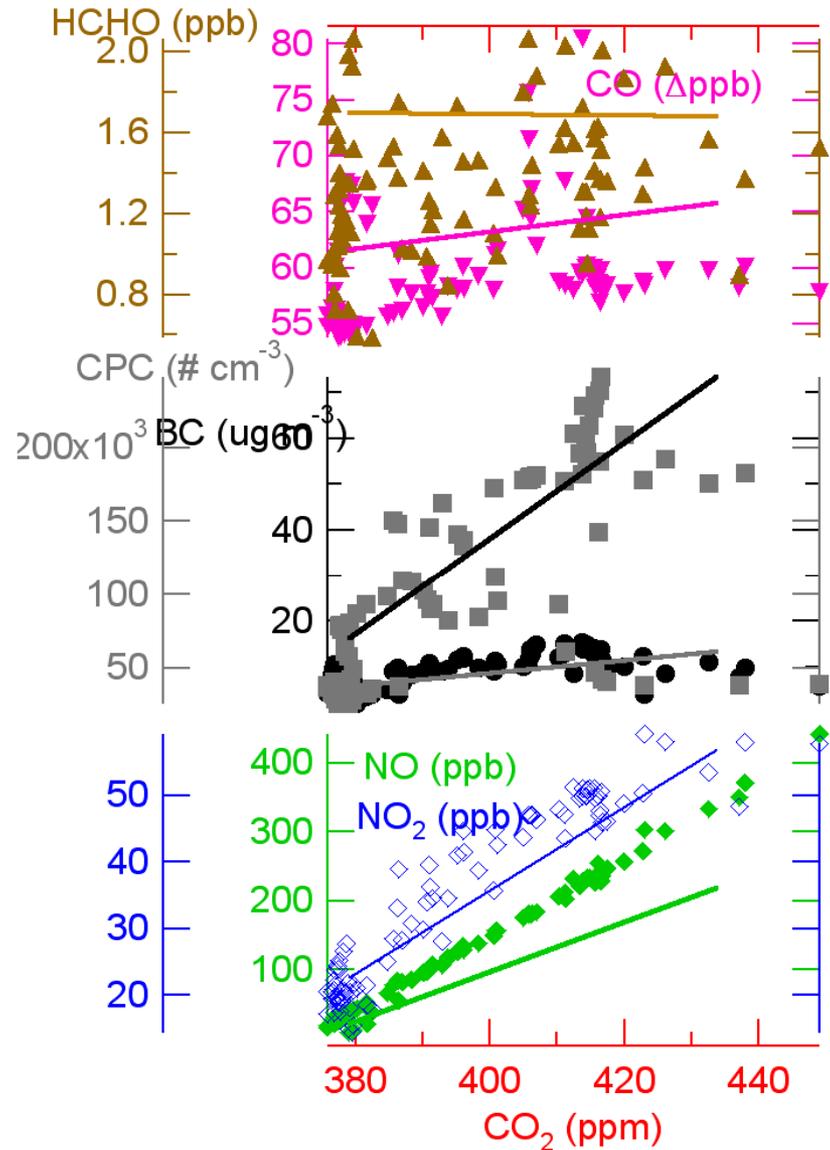
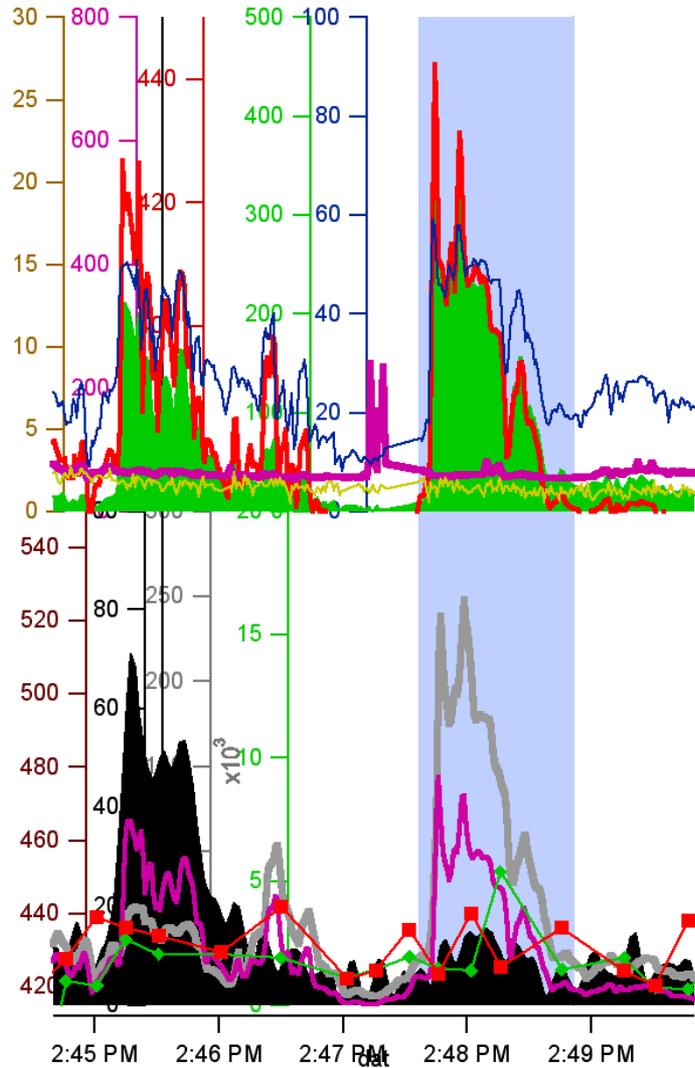
# UNAUNA



# UNAUNA Take-Off Data Example 1



# UNAUNA Take-Off Data Example 2



# Measurements: Airline/Airport (2)

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## Jet Emissions testing for Speciation (JETS) - APEX2

- **August 2005 with Southwest at Oakland**
- **Aircraft/engine combination**
  - **B737-300 with CFM56-3B1 engine**
  - **B737-500/700 aircraft with CFM56-7B24 engine**
- **Measurement team**
  - **AEDC**
  - **ARI**
  - **EPA**
  - **NASA**
  - **UCR**
  - **UMR**

# Measurements: Airline/Airport (3)

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## APEX3

- **October/November 2005 with Continental and FedEx at Cleveland Hopkins**
- **Potential aircraft/engine**
  - **B737-300/500 with CFM56-3 engine**
  - **B737-700/800/900 with CFM56-7 engine**
  - **B757-300 with RB211-535 engine**
  - **ERJ135/145 with AE3007 engine**
  - **A300-600 with PW4158 engine**
- **Measurement team**
  - **ARI**
  - **EPA**
  - **NASA**
  - **UMR**

# Particle Emissions Modeling

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- **Sampling system: probe, line**
- **Combustor**
- **Hot section**
- **Plume: ground, altitude**
- **Atmosphere: local, regional, global**
- **Health**
- **Inter-relationship**

# Most Important Impact?

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- **Health effects**
  - **Direct respiration**
- **Local air quality**
  - **Effects on local chemistry, smog, visibility**
- **Climate change**
  - **Same properties? but at altitude conditions**

# Most Important Parameter?

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- **What to be reduced, limited, controlled**
  - **Mass**
  - **Number (what size range)**
  - **Composition (what size range, what species)**
- **What technology**
  - **Fuel**
  - **Combustor**
- **What standardized methodology**
  - **non-volatile**
  - **volatile**

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**Significant progress in the past decade**  
**Sound research critically needed**

**[particles.grc.nasa.gov](http://particles.grc.nasa.gov)**

**Any Questions?**