

Partners: UMR, MIT, Georgia Tech, U. Illinois
AEDC, Aerodyne, SWRI, HVL Assoc.

Volatile aerosol in gas turbine emissions

Donald Hagen, Philip Whitefield and Prem Lobo
Center of Excellence for Aerospace Particulate Emissions Reduction Research
G-7 Norwood Hall, University of Missouri – Rolla, Rolla, MO 65409, USA

Objectives:

To characterize particle and trace gas precursor species from several CFM56 class 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 current in-service turbofan engines.

Participants:

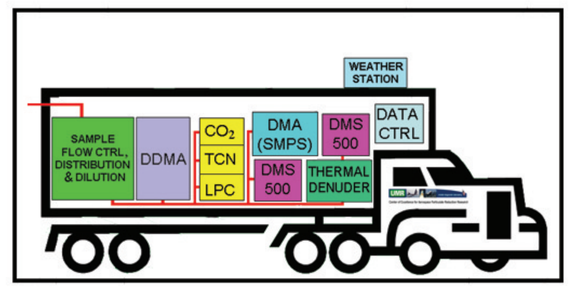
AEDC, ARI, CARB, EPA, NASA (GRC, LaRC), UCF, UCR, UMR

Observers

Boeing, GE

Instrumentation

Cambustion DMS500 (2)
DMA
TSI CNC
CO_2 detector
Weather station



Test Location

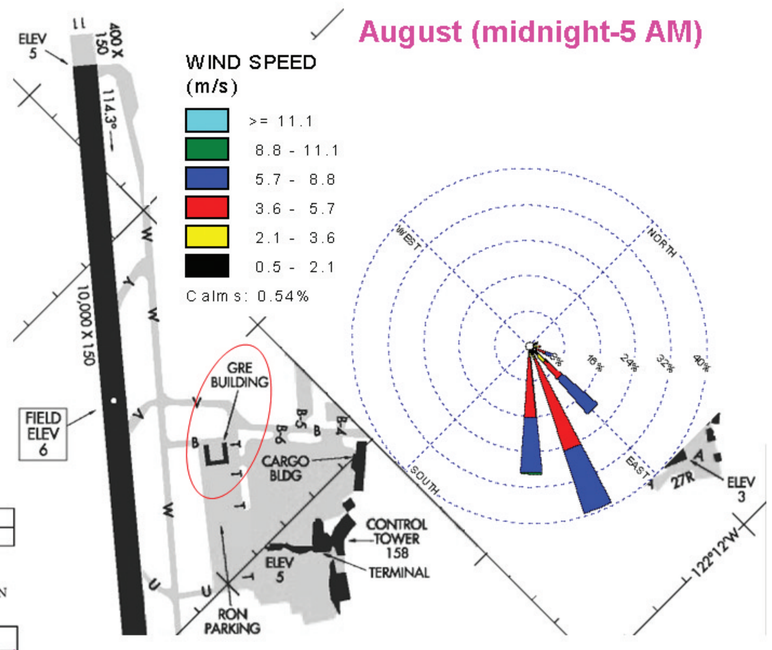
Oakland Airport, Ground Runup Enclosure
Aug. 23-25, 2005

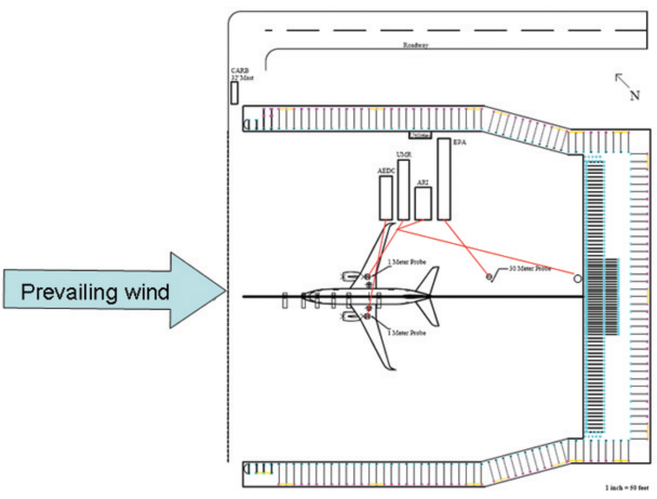
Sponsors:

NASA, EPA, FAA, CARB

Manager:

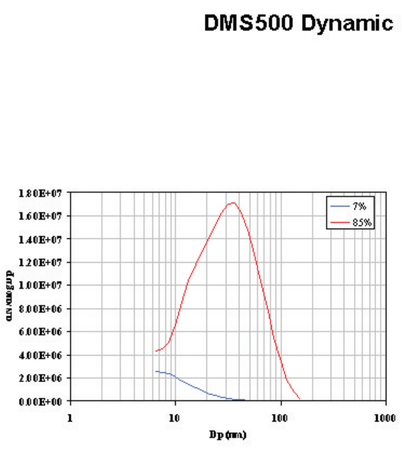
Dr. Philip Whitefield (UMR)

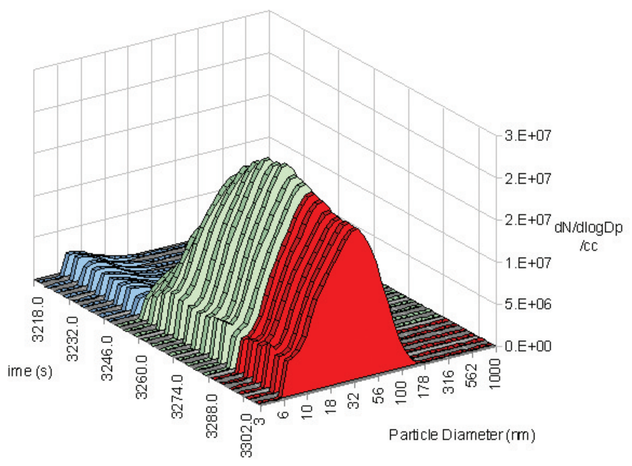




Parameters measured (total and non-volatile aerosol)

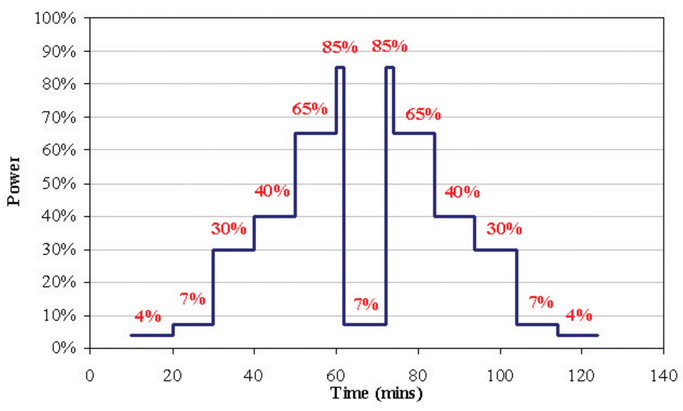
Dgeom – number based geometric mean diameter
Sigma – geometric standard deviation
Dgeom M – mass (volumetric) based geometric mean diameter
EIn – number based emission index
EIm – mass based emission index

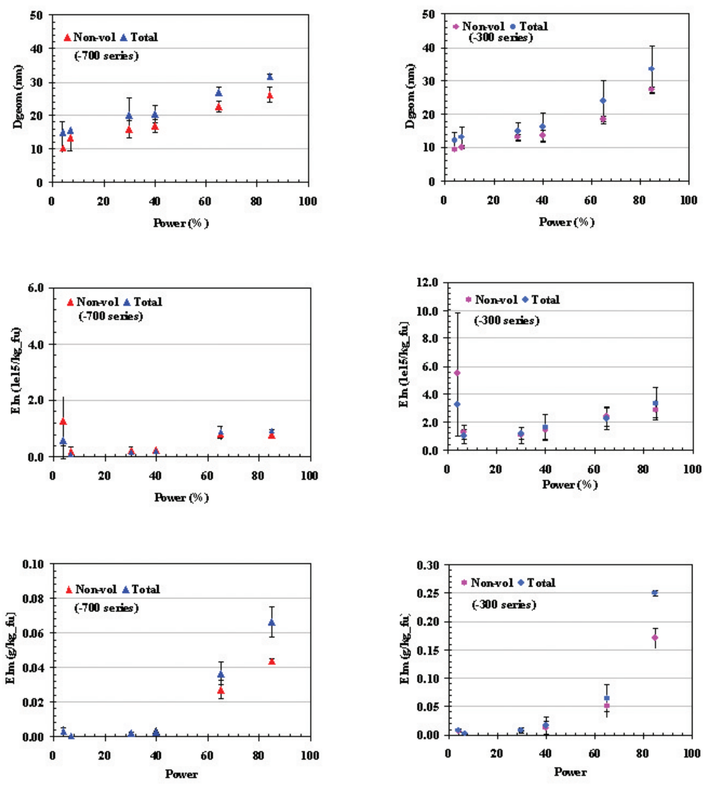


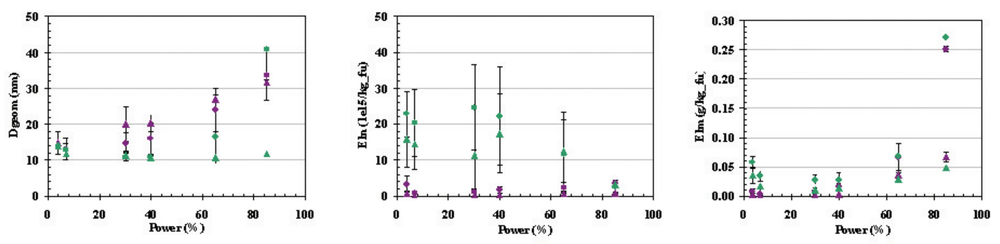


List of engines tested and associated airframes

Date	Aircraft Tail No	Airframe	Engine
August 23, 2005	N435WN	B737-700	CFM56-7B22
August 24, 2005	N353SW	B737-300	CFM56-3B1
August 24, 2005	N695SW	B737-300	CFM56-3B2
August 25, 2005	N429WN	B737-700	CFM56-7B22







700 (1m) 300 (1m) 300 (50m) 700 (50m)

For 300 series 1m Dgeom increases w power, 50m Dgeom has minimum at mid power and strong max at high power. Error bars overlap; no statistically significant difference between 1m and 50m.For 700 series 1m Dgeom increases with power; 50m ~ constant but with weak minimum at mid power, 1m & 50m agree at idle. Dgeom is significantly smaller at 50m.Plume processing evident for the 700 series. Small particle mode pulls Dgeom down. The engine types differ.

Much higher number-based EIn (by factor 40) at 50m and at low and mid power; overlap at highest power. Larger increase in EIn for 300 series. Gas-to-particle conversion occurs in the plume.

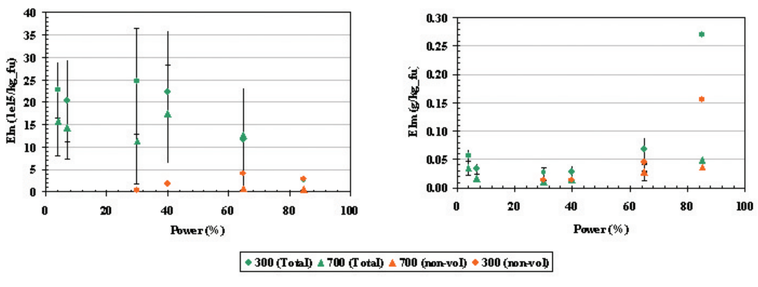
For the 300 series, small increase in EIm at 50m at all powers.
For the 700 series, small increase in EIm only at low power.
Gas-to-particle conversion produces a large number of new particles, but only a small increase in mass.

Engine Averages

Case							
Dgeom (nm)	Min	±%	Max	±%	Avg	±%	Slope
NonVol 1m	10	7	21	18	14	14	+
NonVol plume	7	3	21	15	12	10	+
Total 1m	13	20	28	15	18	19	+
Total plume	11	7	21	39	13	15	±
IPCC(*)	10		30				
Sigma	Min	±%	Max	±%	Avg	±%	Slope
NonVol 1m	1.47	3	1.96	2	1.67	2	+
NonVol plume	1.22	4	2.06	1	1.62	3	+
Total 1m	1.41	7	1.79	4	1.58	4	+
Total plume	1.25	3	1.70	17	1.39	5	+
GRL(**)	1.66		1.73				
DgeomM (nm)	Min	±%	Max	±%	Avg	±%	Slope
NonVol 1m	33	30	70	14	50	19	+
NonVol plume	20	18	83	24	51	21	+
Total 1m	28	23	67	18	41	18	+
Total plume	16	13	66	39	32	28	+
EIn (10^15/kg_fuel)	Min	±%	Max	±%	Avg	±%	Slope
NonVol 1m	0.67	64	4.1	61	1.7	56	-
NonVol plume	0.54	68	17.9	32	6.0	49	-
Total 1m	0.68	87	10.2	130	4.5	129	±
Total plume	7.95	85	28.0	38	16.1	28	-
IPCC(*)	0.30		50.0				
EIm (g/kg_fuel)	Min	±%	Max	±%	Avg	±%	Slope
NonVol 1m	0.002	69	0.060	55	0.016	49	+
NonVol plume	0.004	74	0.045	75	0.014	62	+
Total 1m	0.002	84	0.084	55	0.023	61	+
Total plume	0.012	65	0.078	52	0.031	47	±
IPCC(*)	0.010		0.200				
		(*) - IPCC Report, Aviation and the Global Atmosphere (1999)					
		(**) - Petzold et al., Geophys. Res. Let. 30, 1719 (2003)					

The data for the 1m total and non-volatile aerosol are in good agreement with each other except for a difference observed at the highest power condition for Dgeom and EIm. Good agreement implies no condensation before sample capture at the 1m location.

Differences in Dgeom and EIm at the highest powers indicate minor line processing under these conditions may have taken place.



Total EIn exceeds Non-Volatile at most powers, overlap at max power.
Particle number excess due to gas-to-particle conversion of volatile material.Larger effect for 300 series.

Total EIm tends to exceed Non-volatile mass, but error bars overlap.

Result highlights for CFM56 engines (averages for all powers and engines studied)

- Particle diameters fall into the range from 12 to 30 nm. Number and mass based geometric mean diameters increase with engine power.
- Number based emission indices exhibit a minimum at low to mid power, range from 0.5 to 28x10^{15}/kg_fuel, and increase in the plume.
- Mass based emission indices tend to increase with power and range from 0.002 to 0.25 g/kg_fuel.

Acknowledgements

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