Commercial Aircraft Particle Emissions: Preliminary JETS/APEX-2 Observations

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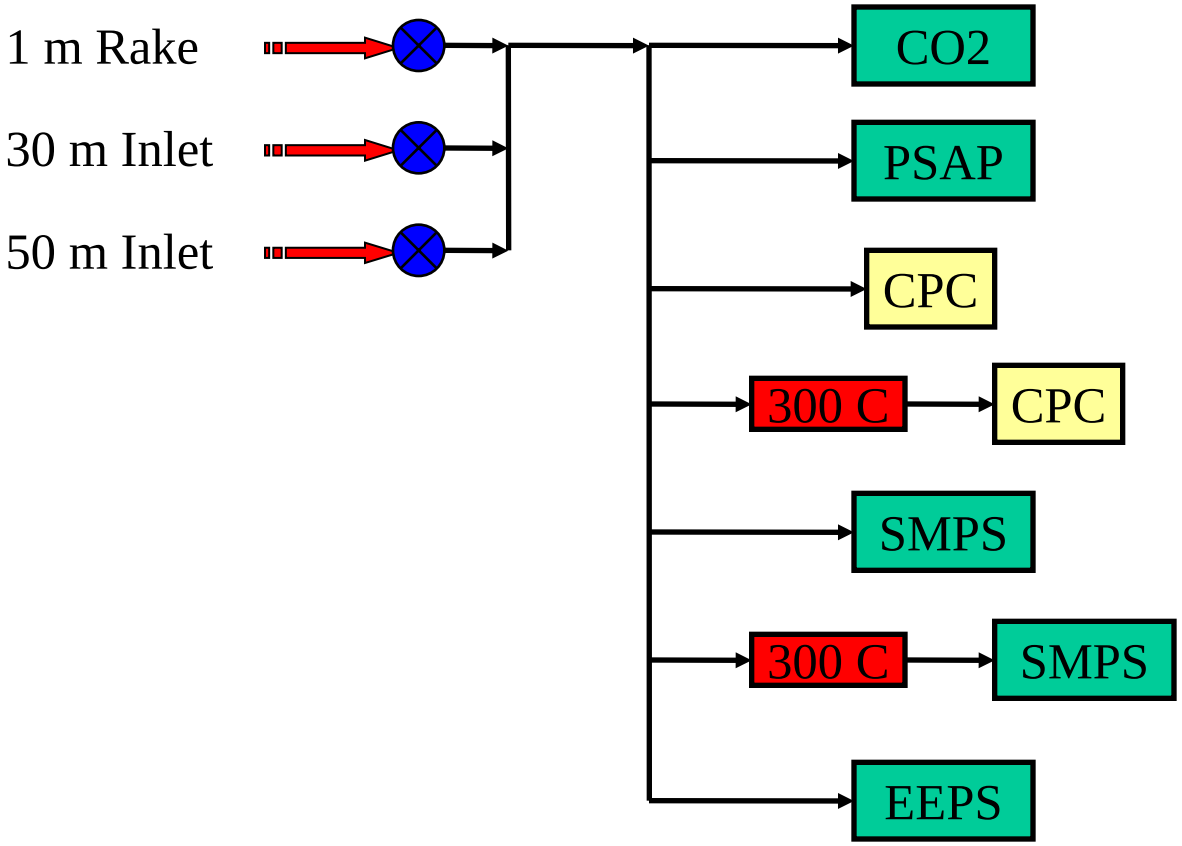
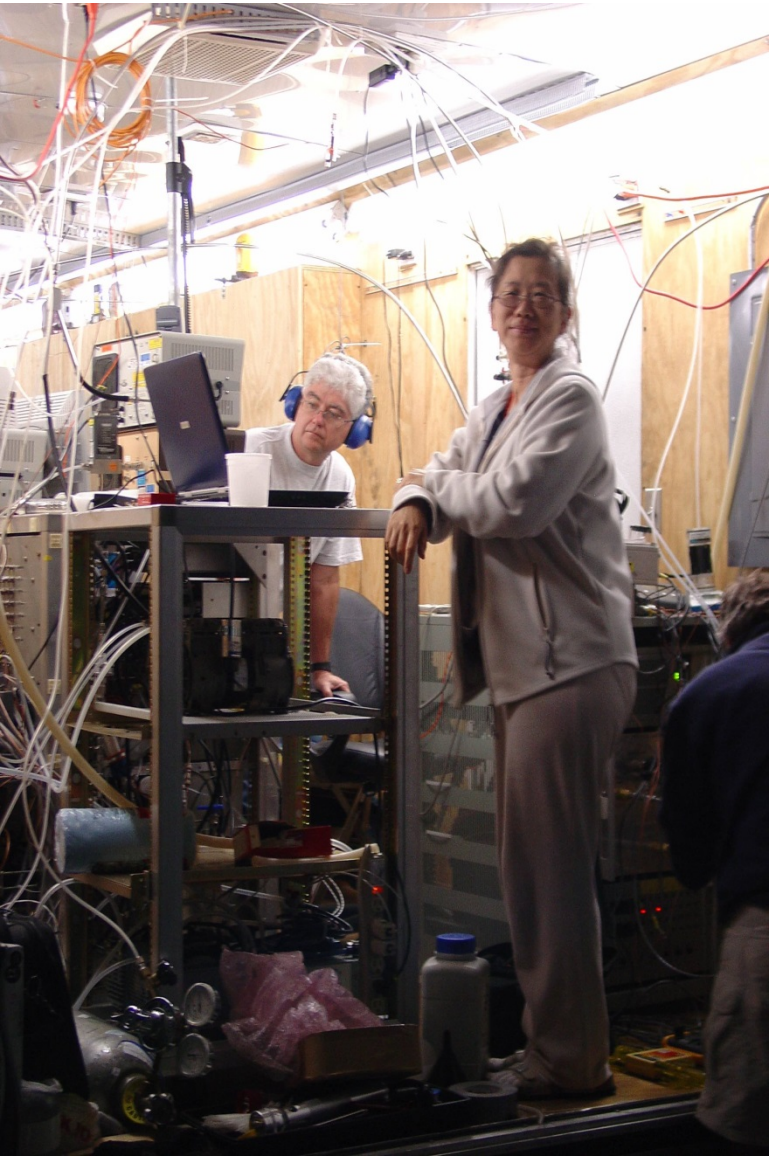
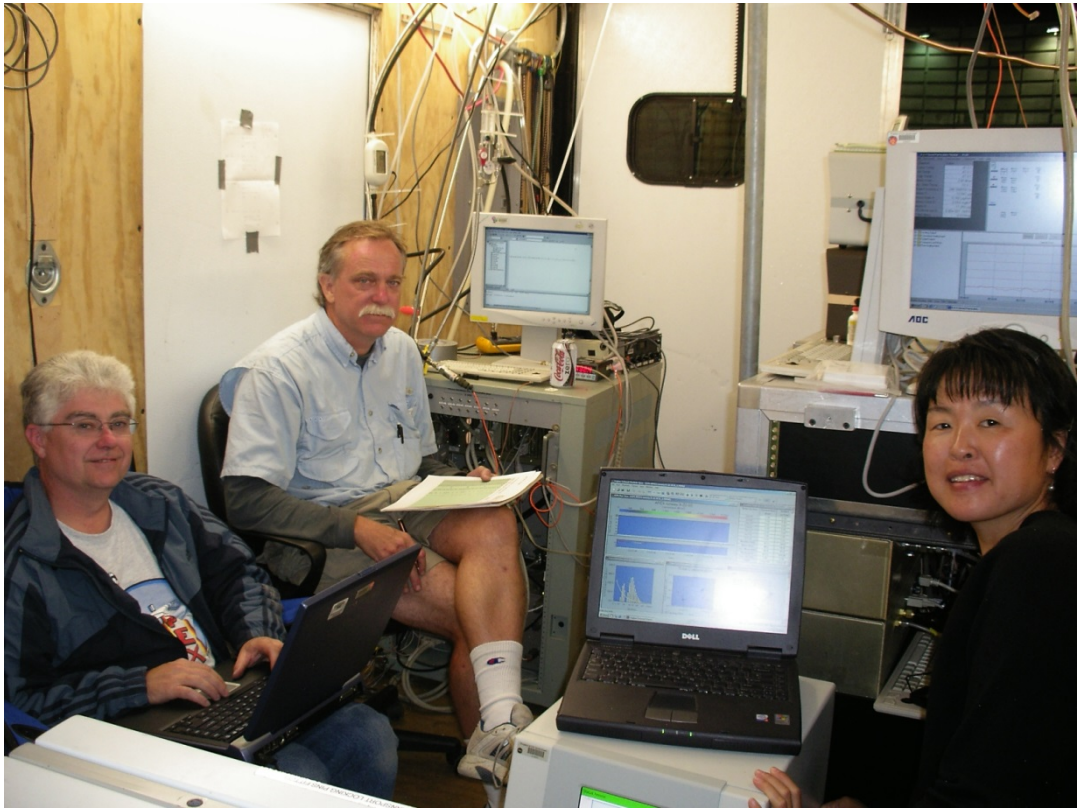
NASA Aerosol Characterization Instruments



NASA Deployment Team

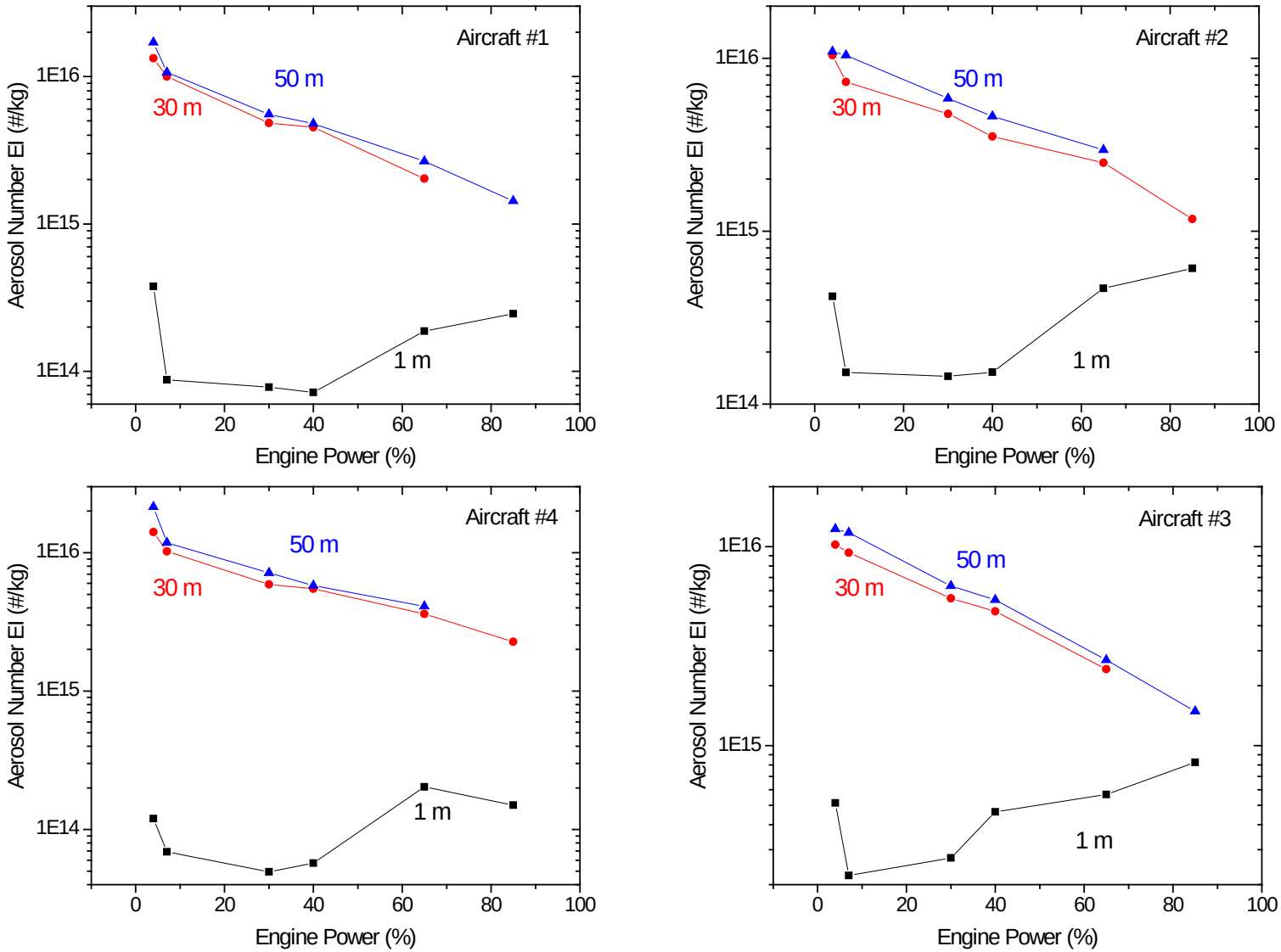




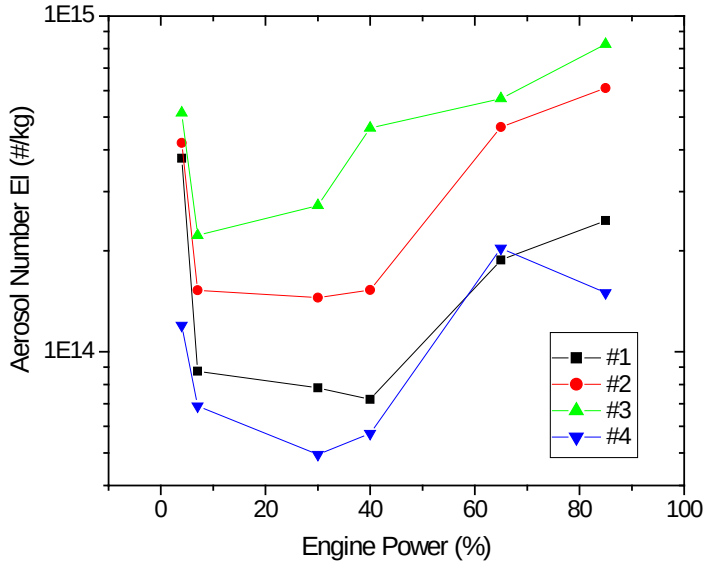
Special Thanks to UMR for Accommodations

Multi-tipped Sampling Rake and Stand

Aerosol Number Emissions



Aerosol Number Emissions



<u>1 meter Inlet</u>

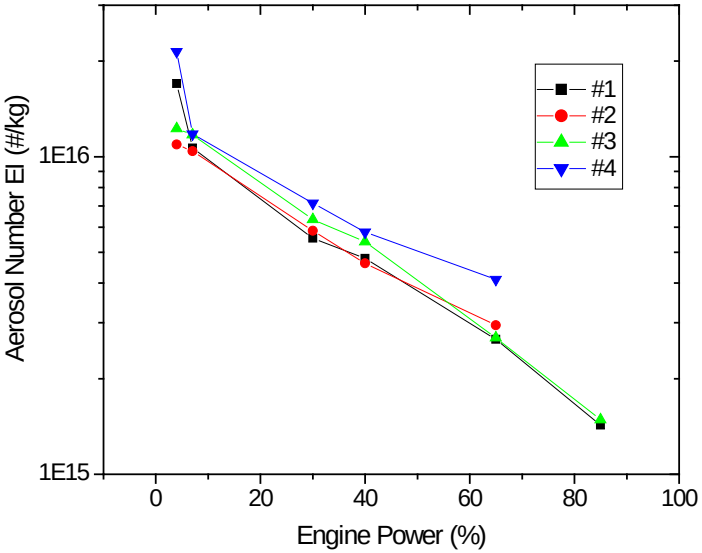
CFM56-7B24: 0.6 to 2 x 10^{14} kg^{-1}

CFM56-3B: 1.5 to 8 x 10^{14} kg^{-1}

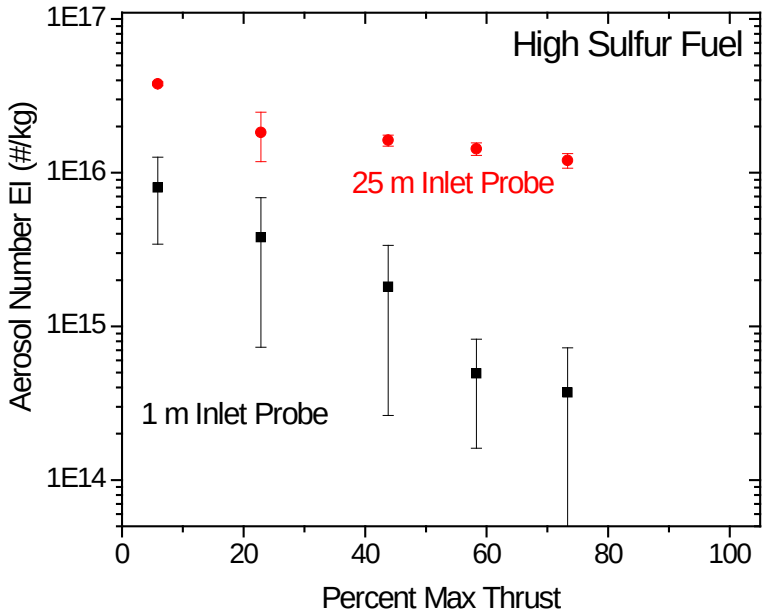
<u>50 meter Inlet</u>

CFM56-7B24: 2 to 20 x 10^{15} kg^{-1}

CFM56-3B: 1 to 15 x 10^{15} kg^{-1}



Aerosol Number Emissions



RB-211

~0.5 - 5 x 10^{15} kg^{-1} nonvolatile

10 - 50 x 10^{15} kg^{-1} volatiles

EI highly dependent on ppmS

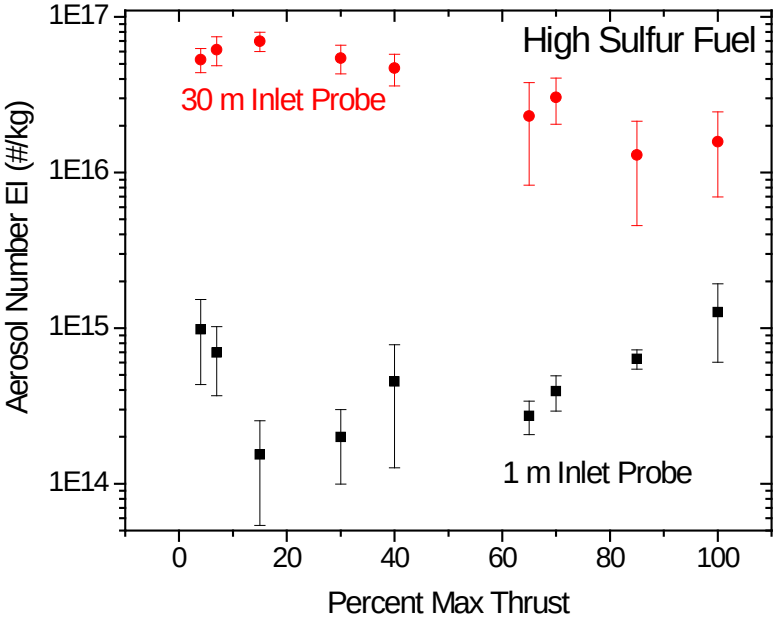
CFM-56

~0.5 - 2 x 10^{15} kg^{-1} nonvolatile

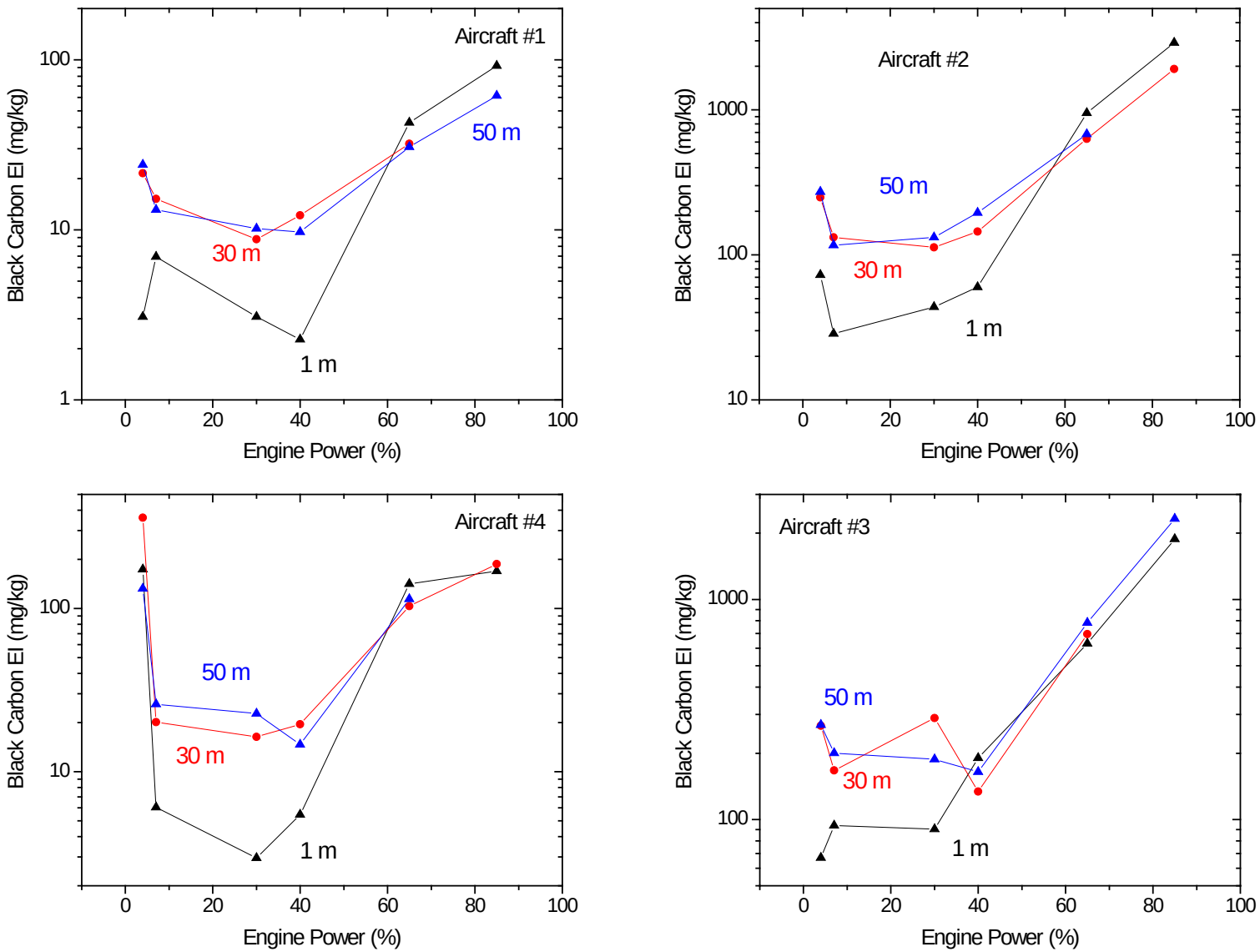
10 - 70 x 10^{15} kg^{-1} volatiles

EI highly dependent on ppmS

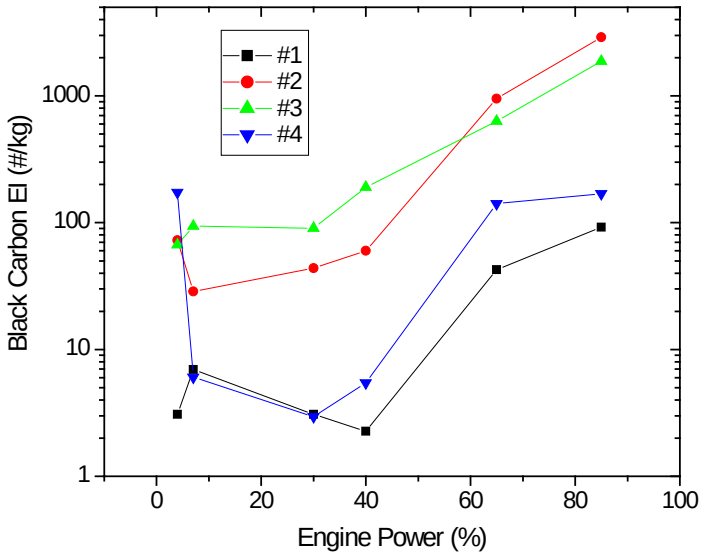
1 - 3 x 10^{7} new particles/cc!



Black Carbon Emissions



Black Carbon Emissions



1 meter Rakes

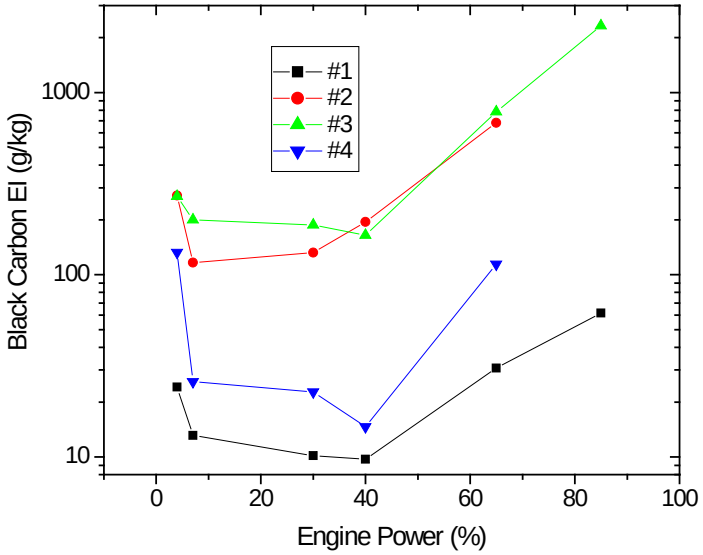
CFM56-7B24: 5 to 200 mg/kg

CFM56-3B: 50 to 1000 mg/kg

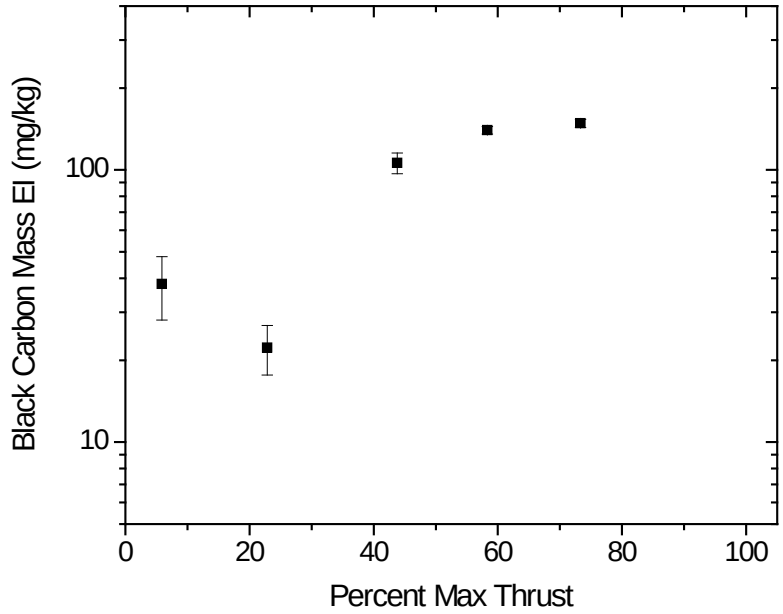
50 meter Inlet

CFM56-7B24: 10 to 100 mg/kg

CFM56-3B: 100 to 2000 mg/kg



Black Carbon Emissions

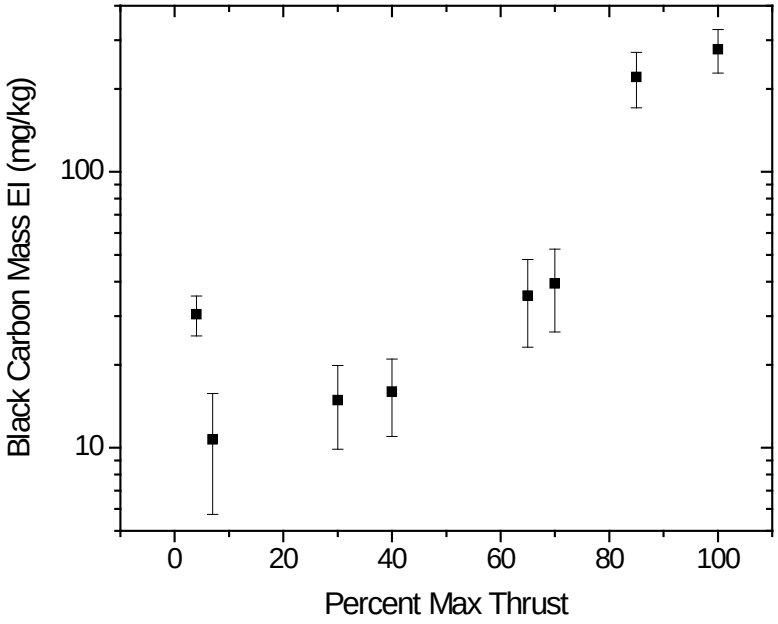


RB-211

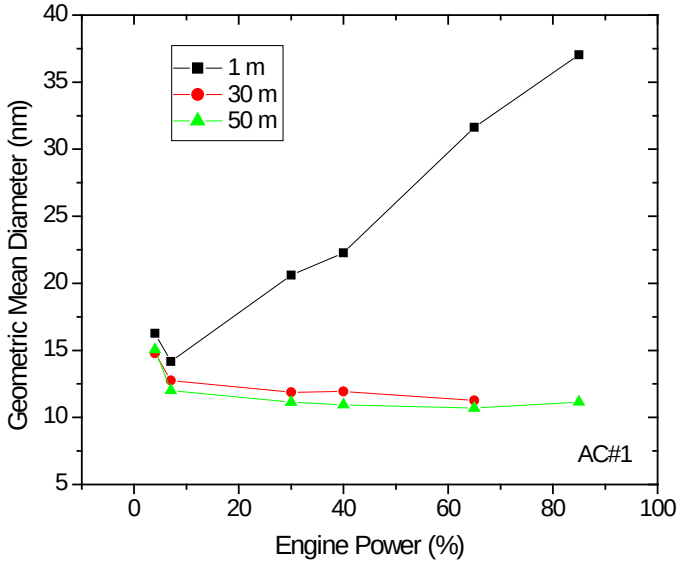
~20-200 mg/kg fuel

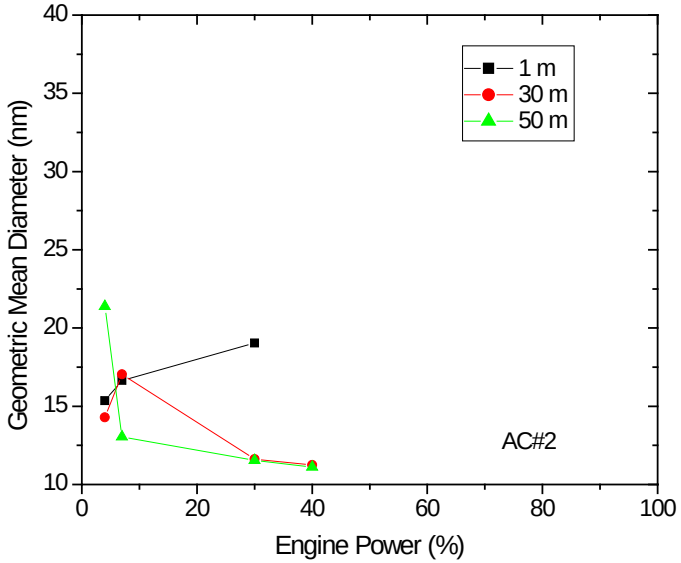
CFM-56

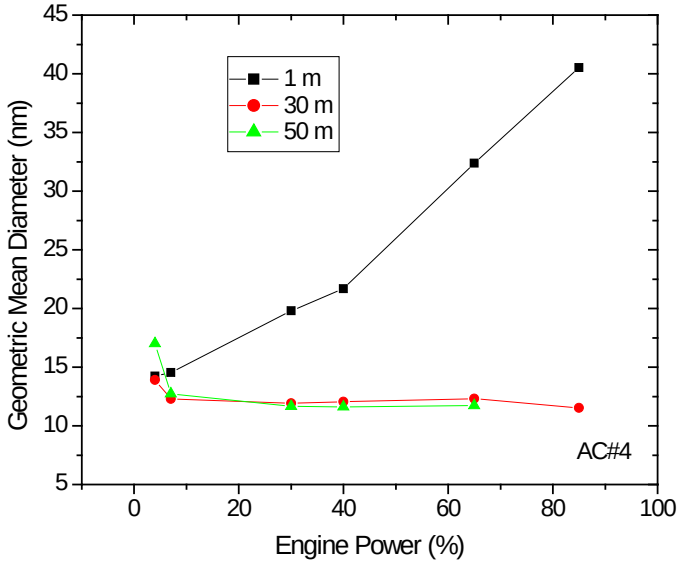
~10-300 mg/kg fuel

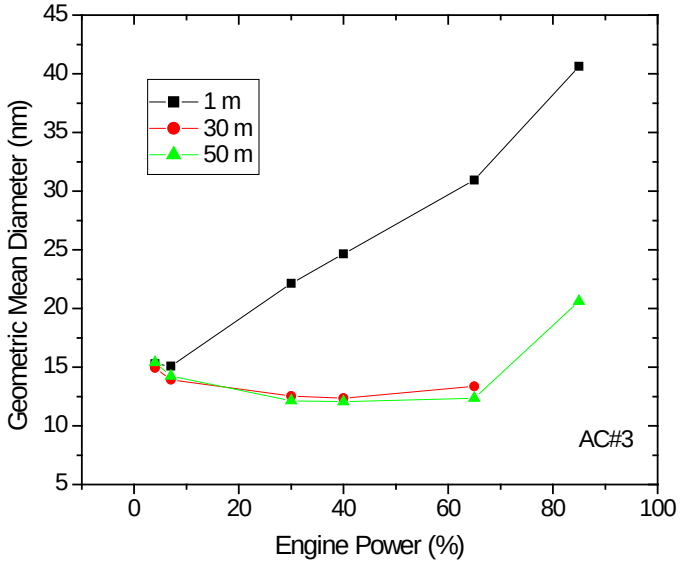


Aerosol Size Diameter

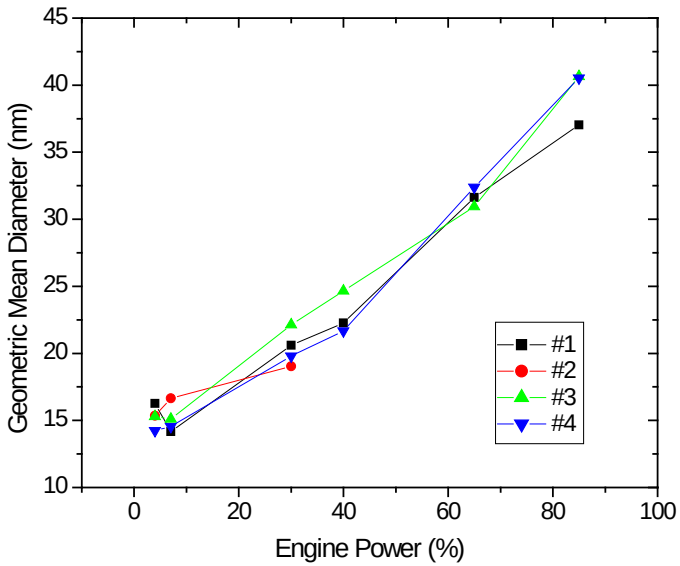








Aerosol Size Diameter



<u>1 meter Rakes</u>

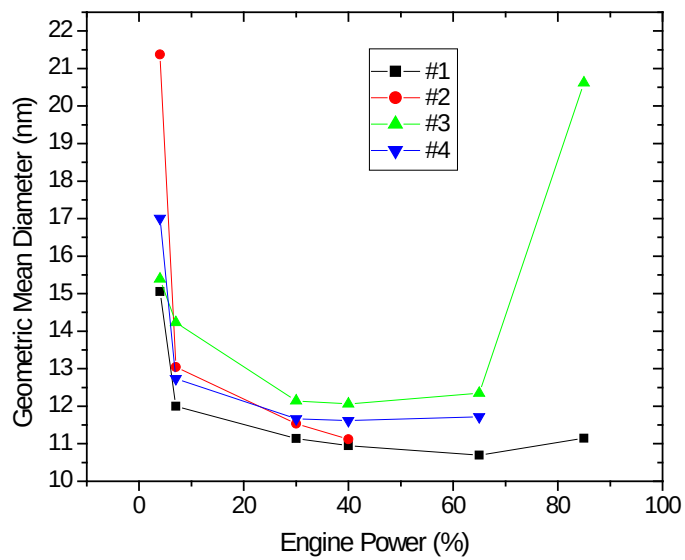
CFM56-7B24: 15 to 40 nm

CFM56-3B: 15 to 40 mg/kg

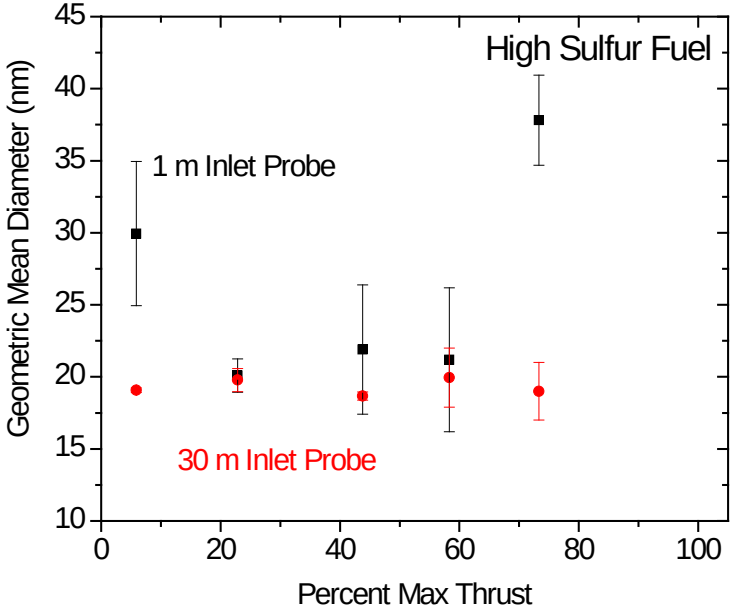
<u>50 meter Rakes</u>

CFM56-7B24: 10 to 20 nm

CFM56-3B: 11 to 20 nm



Aerosol Size Diameter



RB-211

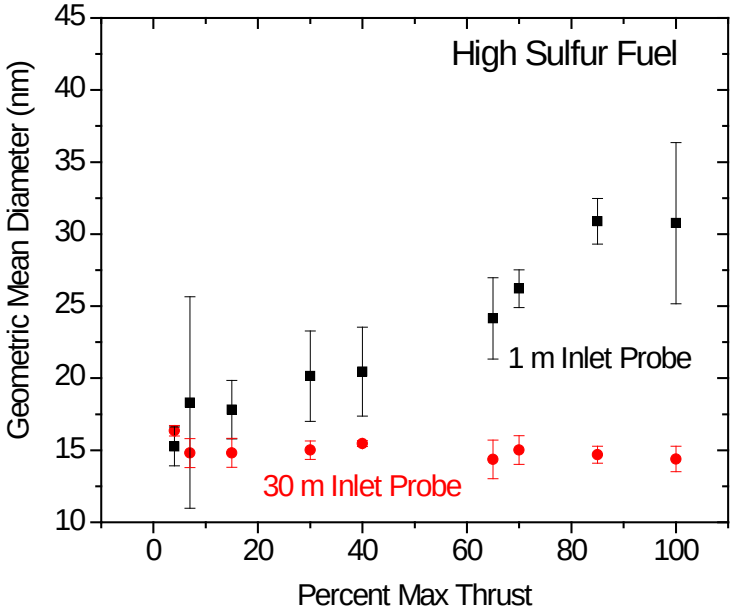
GMD ~ 20 – 40 nm @ 1 m

GMD ~ 15 – 20 nm @ 25 m

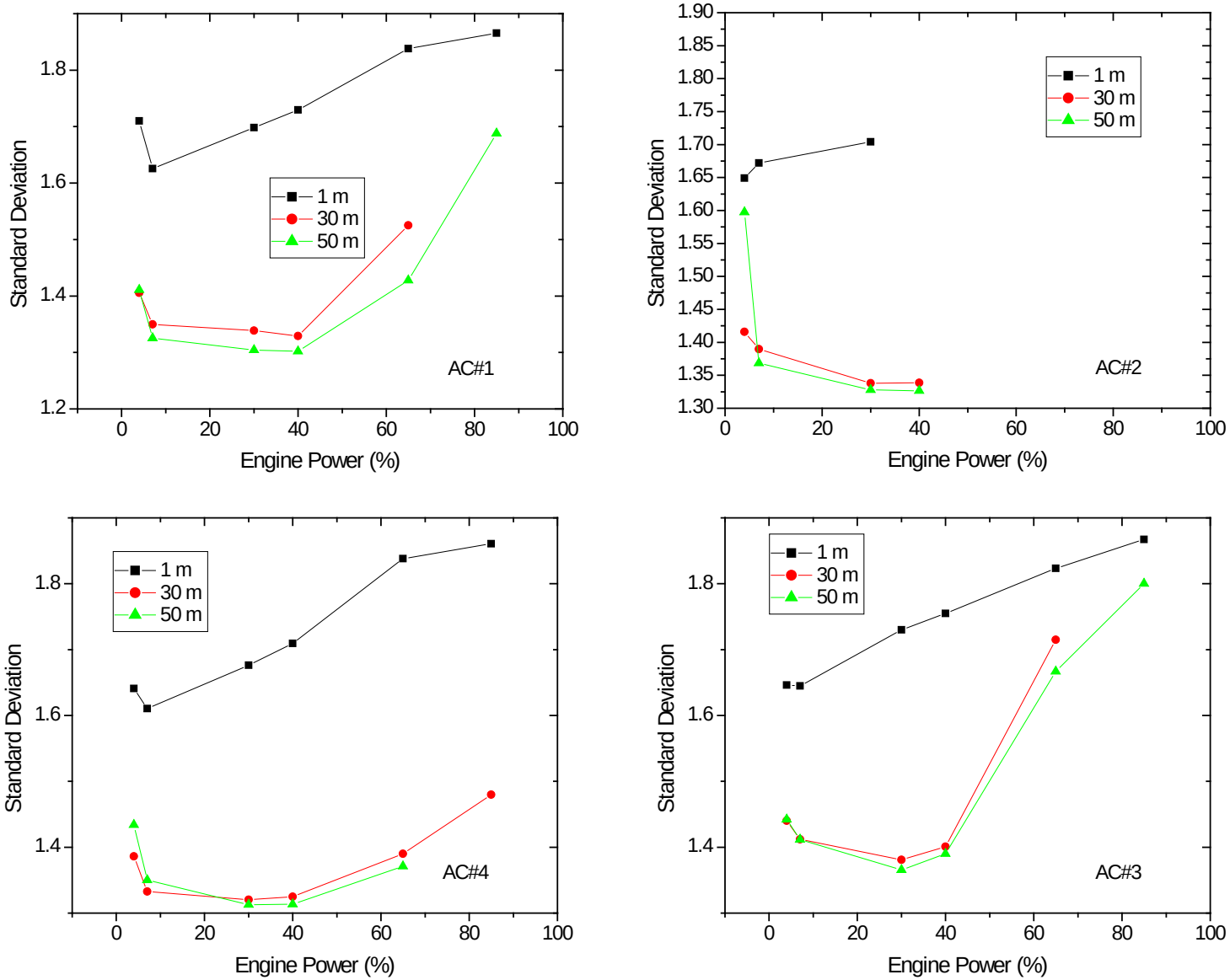
CFM-56

GMD ~ 15 - 35 nm @ 1 m

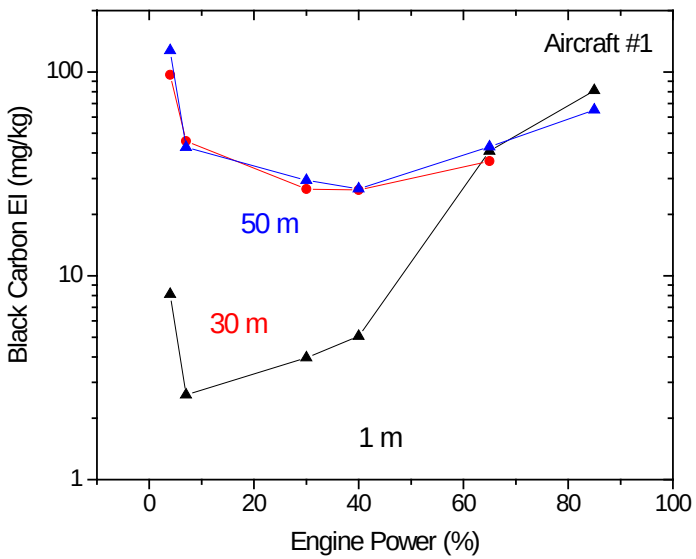
GMD ~ 15 nm @ 30 m

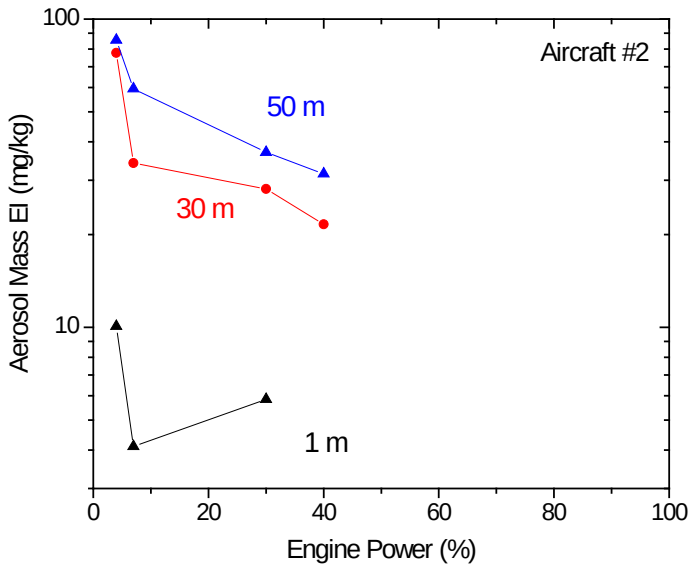


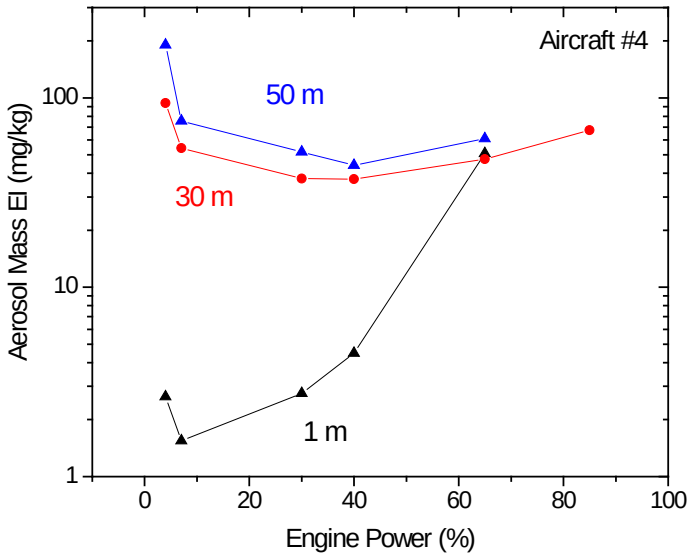
Standard Deviation of Size Distribution

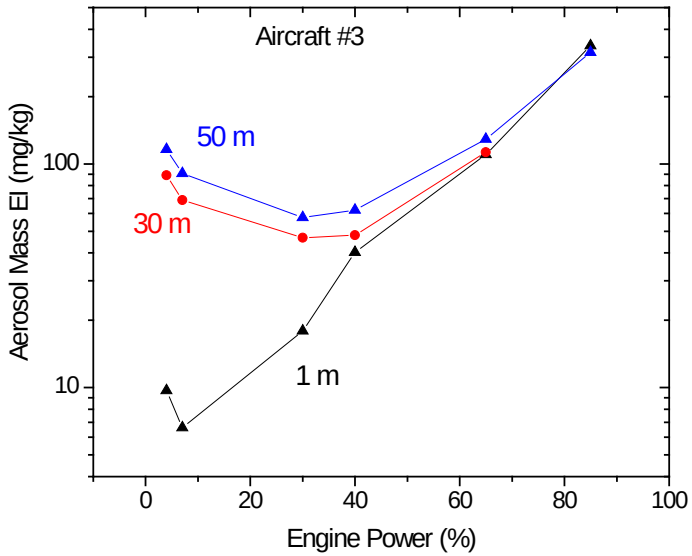


Aerosol Mass Emissions

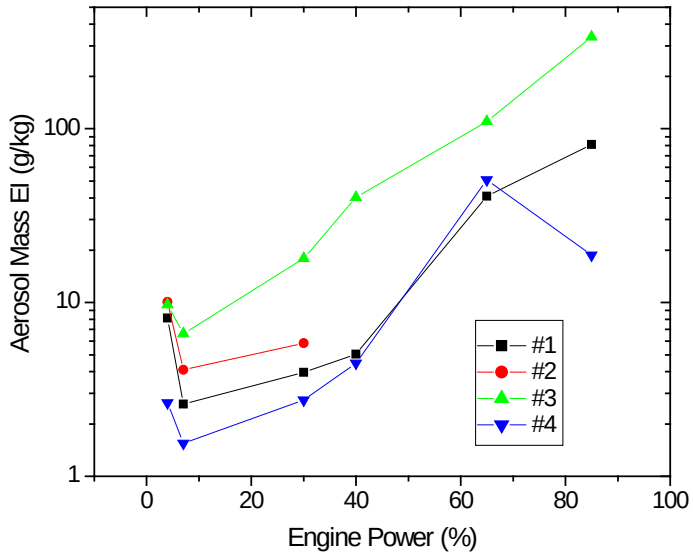


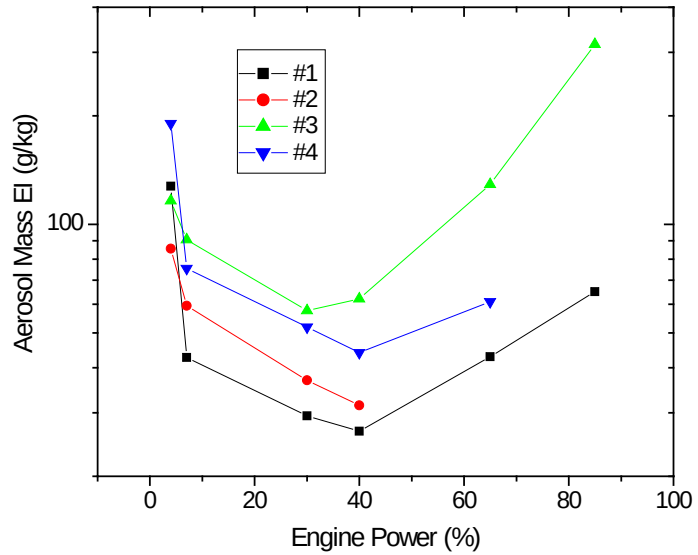






Aerosol Mass Emissions





<u>1 meter Rakes</u>

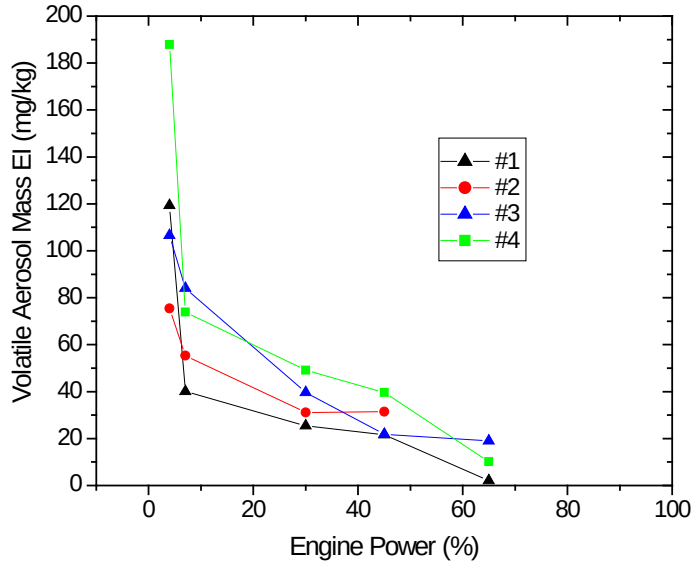
CFM56-7B24: 2 to 100 mg/kg

CFM56-3B: 10 to 400 mg/kg

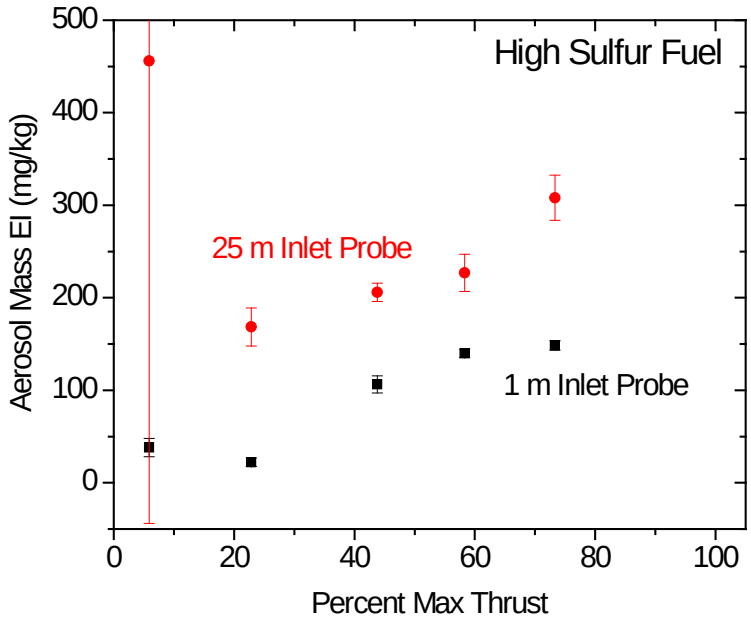
<u>50 meter Rakes</u>

CFM56-7B24: 20 to 200 mg/kg

CFM56-3B: 10 to 400 mg/kg



Aerosol Mass Emissions



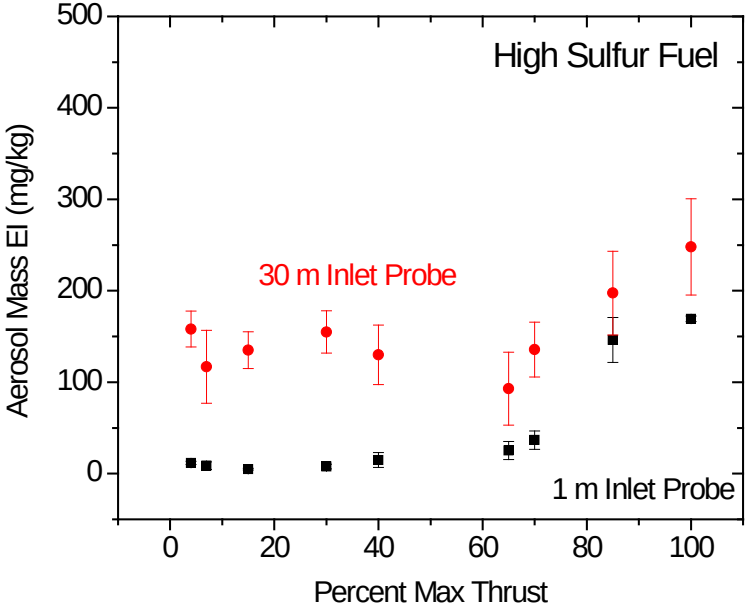
RB-211

20 – 1000 mg/kg @ idle

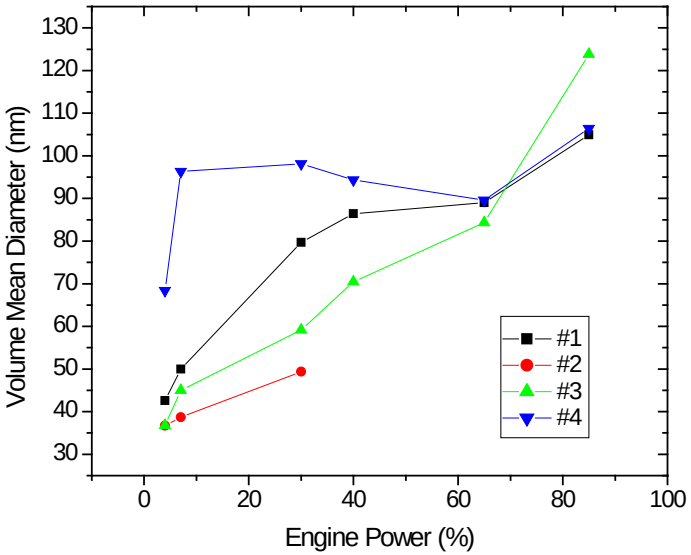
50 –100 mg/kg @ higher powers

CFM-56

50 – 150 mg/kg



Volume Mean Diameters



<u>1 meter Rakes</u>

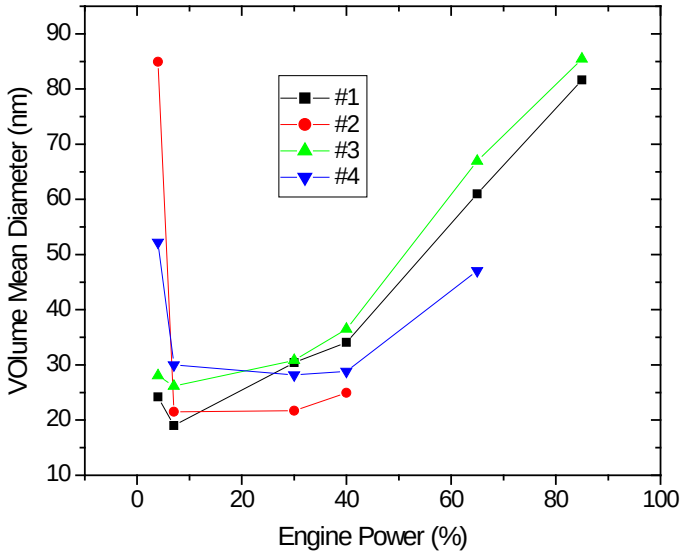
CFM56-7B24: 40 to 105 nm

CFM56-3B: 35 to 125 nm

<u>50 meter Rakes</u>

CFM56-7B24: 20 to 80 nm

CFM56-3B: 20 to 80 nm



Summary of Result to Date

- Modern engines emit 0.1 – 2 x 10^{15} kg^{-1} fuel burned of nonvolatile particles, depending on power setting
- Nonvolatile particle mass emissions range from 10 to 300 mg kg^{-1} and increase with power
- Nonvolatile particle size increases with power, with GMD's ranging from 15 to 45 nm
- Secondary aerosols form rapidly within the plume, with formation rates approaching 10^7 cm^{-3} s^{-1}; nucleation mode evident in aged plumes
- Sulfur and organic species implicated in secondary aerosol formation; RB211 emits > 1000 mg kg^{-1} under some conditions; 200 mg kg^{-1} volatiles common for many engines at idle
- Secondary aerosol number and mass concentrations are highly dependent on fuel S concentrations
- Volatile aerosol variation with fuel S consistent with conversion of $1 \pm 0.5\%$ of fuel S to S(VI)