Development of calibration procedures for non-volatile particulate matter mass measurement methods--status report

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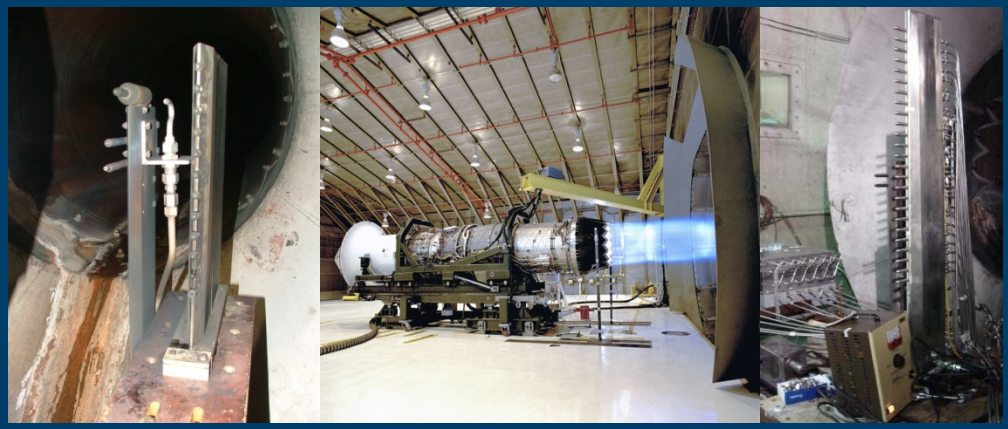

Presented at: SAE E-31 Committee Meeting, Ottawa, Canada, June 6-10, 2011

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Research problem

- Three candidate methods were identified by the SAE E-31 Committee for possible use in an Aerospace Recommended Practice (ARP) for the measurement of non-volatile particulate matter (PM) mass emissions during engine certification. A fourth technique was added later at the request of EPA's Office of Transportation and Air Quality.
- None of these techniques measure PM mass directly, have a standard procedure available to implement the method, or incorporates a process to adequately quality-assure the data collected.
- A program was designed to standardize each method, provide appropriate quality assurance/control procedures, and validate the measurements against a traceable standard method (filter gravimetric).

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Program objectives

- Develop Standard Operating Procedures (SOPs), including quality assurance/quality control checks, for four near-real-time non-volatile particulate matter (black carbon) mass measurement techniques including:
  - Carbon burn-off [i.e., National Institute of Occupational Safety and Health (NIOSH) Method 5040]
  - Multi-Angle Absorption Photometer (MAAP)
  - Laser Induced Incandescence (LII)
  - Photoacoustic analysis (PA)
- Validate all four methods against the filter gravimetric technique using a known black carbon aerosol source (Mini-CAST) indicative of turbine engine exhaust in a controlled laboratory environment
- If possible, determine the sensitivity of these techniques to organic carbon in the test aerosol
- Provide the above information to the SAE E-31 Committee for inclusion in an Aerospace Recommended Practice for the measurement of non-volatile PM mass to be used in future engine certification

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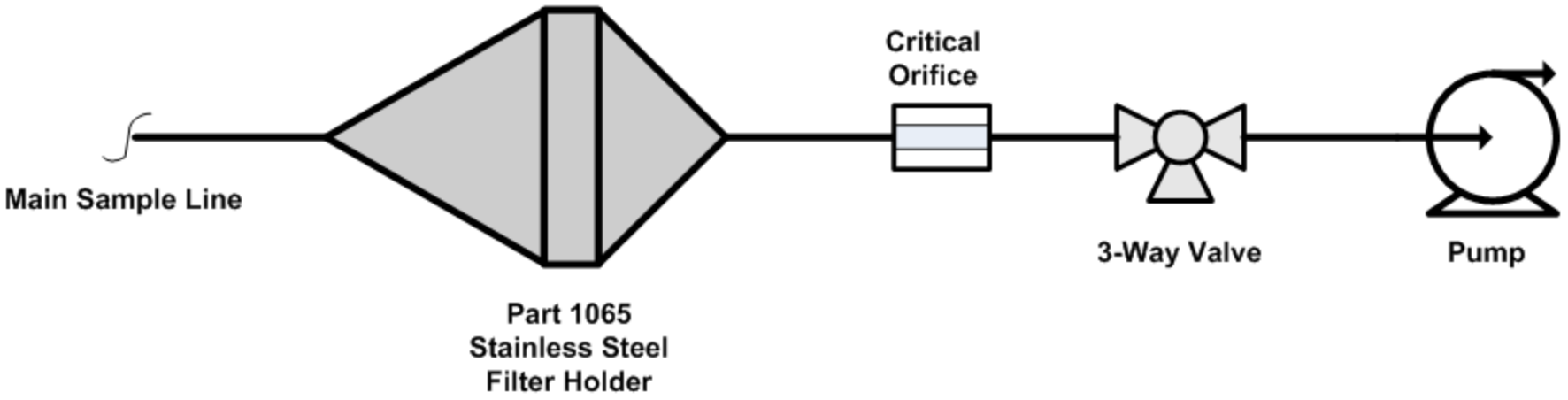
Modifications to NIOSH Method 5040

- Development of specialized sampling train for gas turbine exhaust
- Validation against filter gravimetric technique



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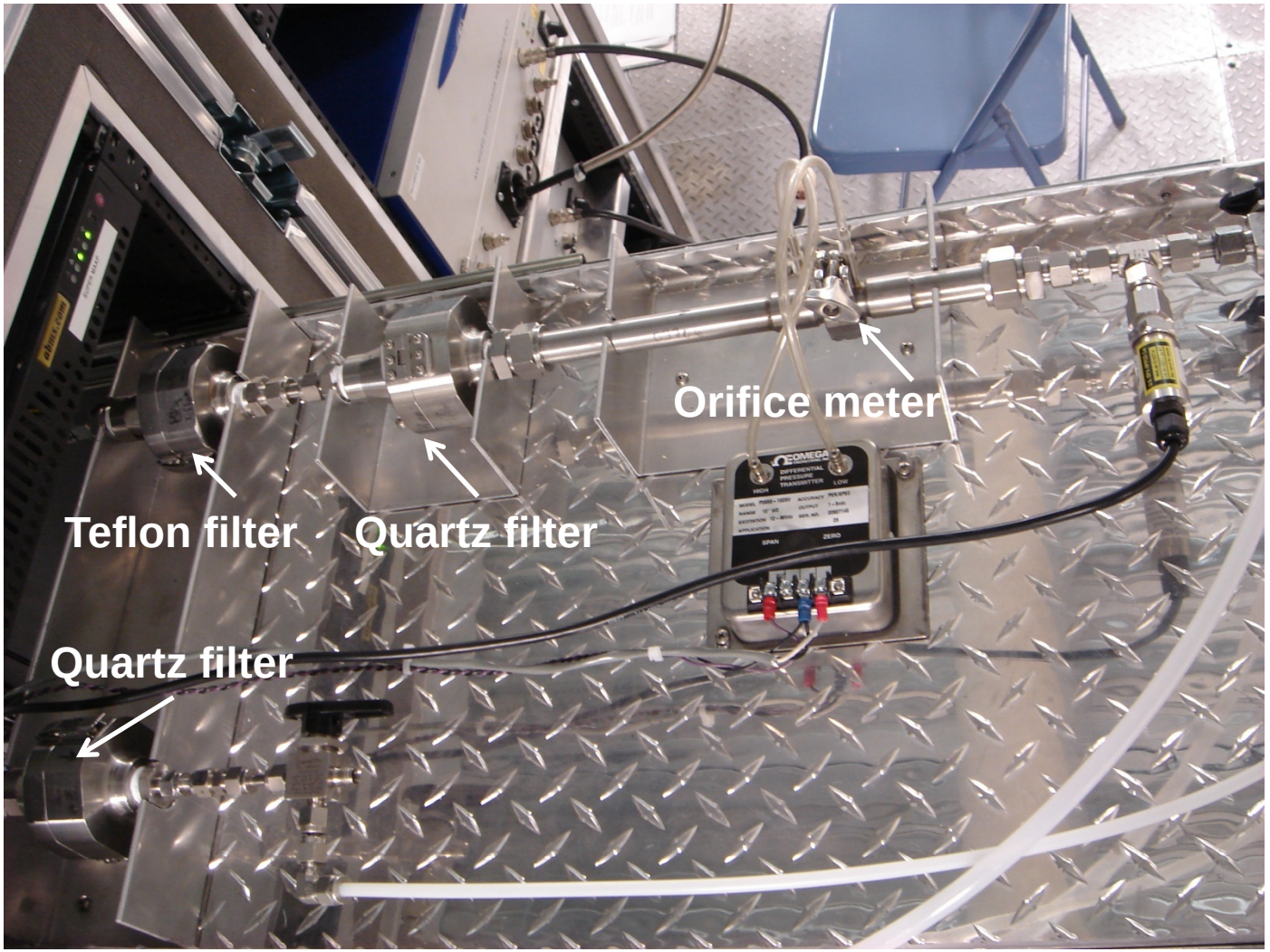
Filter sampling trains



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Modifications to Thermo Scientific Model 5012 MAAP for use in engine certification

- Reduce the flow through the filter tape to extend the time between filter changes
- Isolate the MAAP from the main sampling line during filter changes
- Perform the necessary calculations to determine black carbon (BC) concentration on a 1 Hz basis and log the data
- Calculate appropriate statistics from the calculated BC concentrations
- Provide the ability to implement a manual filter change
- Monitor the percent light transmission in real time so that the operator can determine when a filter change is about to take place
- Allow for and document some type of quality control check to tell the operator the instrument is working properly and ready for use
- Develop an add-on “package” incorporating the necessary changes for use in certification environments

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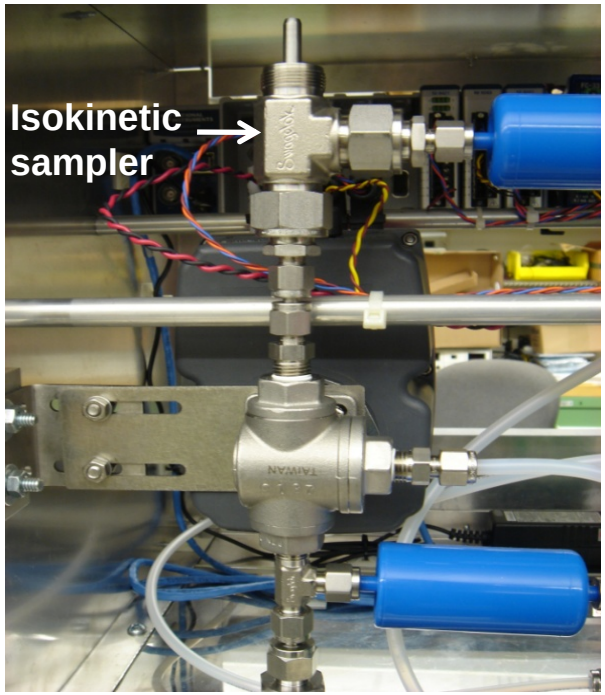
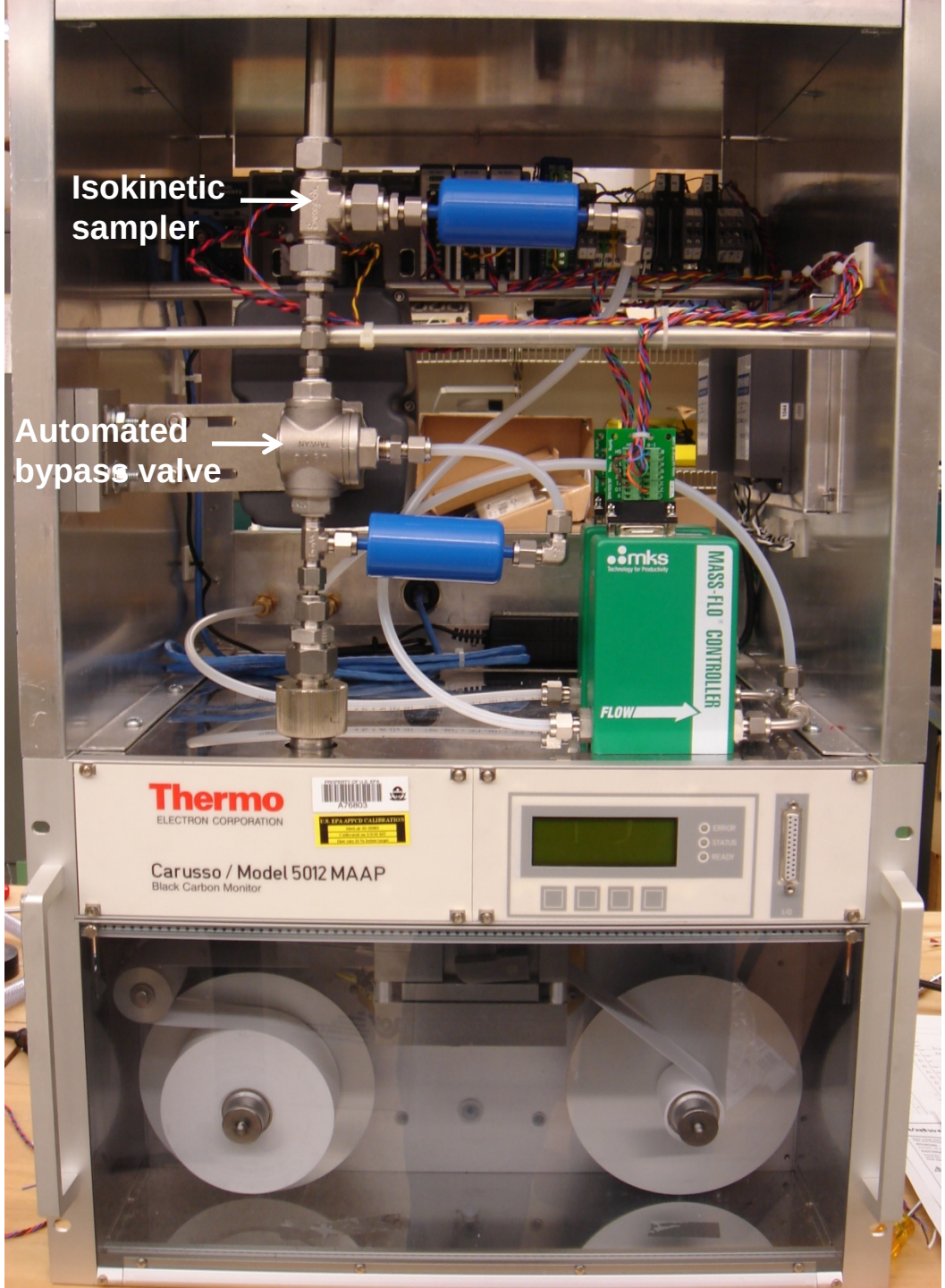
Photos of SuperMAAP hardware modifications





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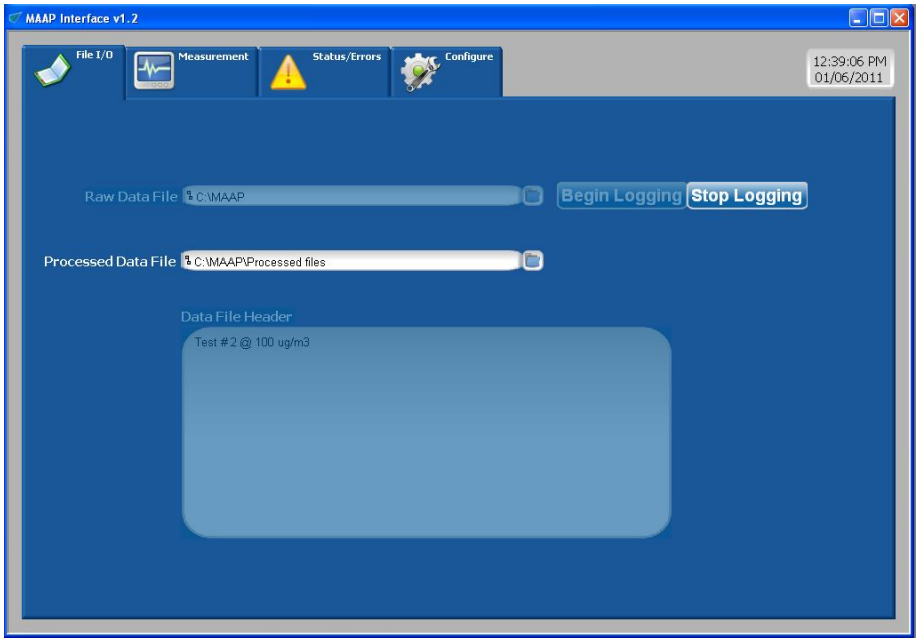
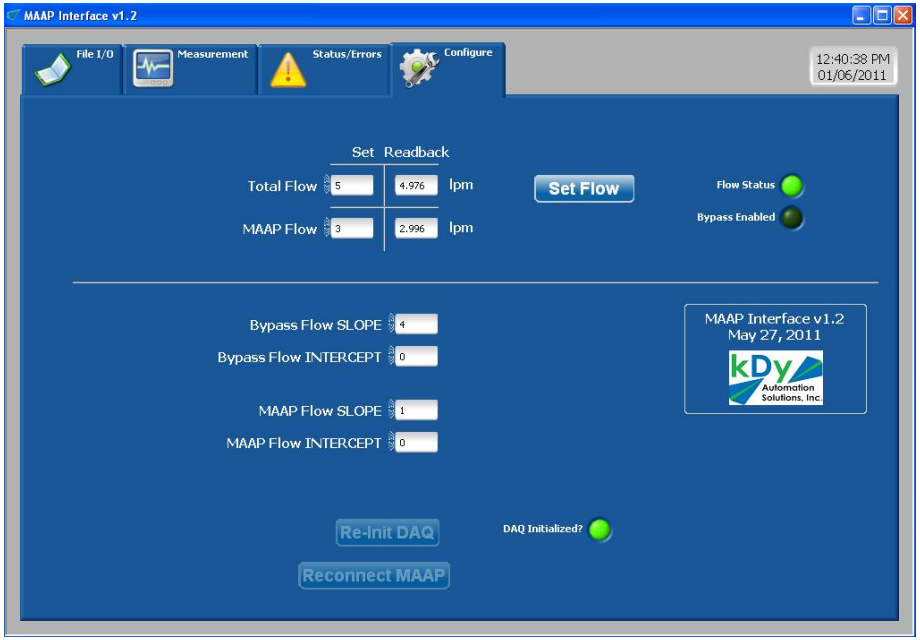
SuperMAAP user interface





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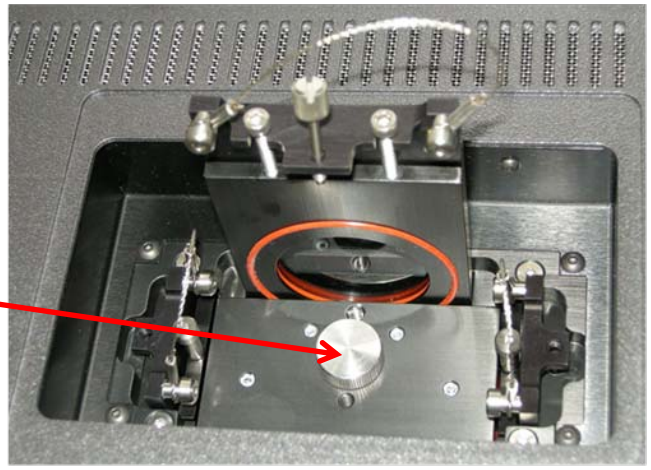
Modifications to Artium Technologies LII 300 Instrument

- Incorporation of a flow meter, filter, and external pump to monitor sample flow rate to the instrument
- Addition of an independent light source to be used as an independent QC check to verify proper instrument operation before starting measurements
- Ability to control instrument from a remote computer
- Procedure added to the firmware package for cell temperature and pressure calibration

Artium LII 300 independent light source



Access port
for independent
light source

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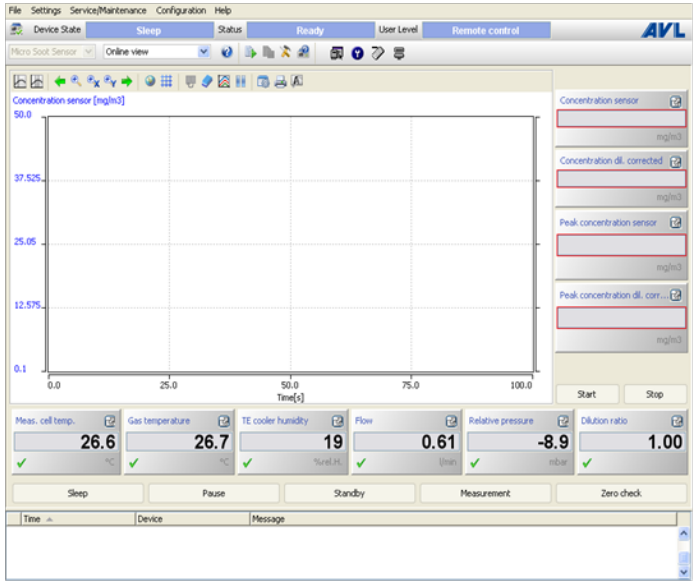
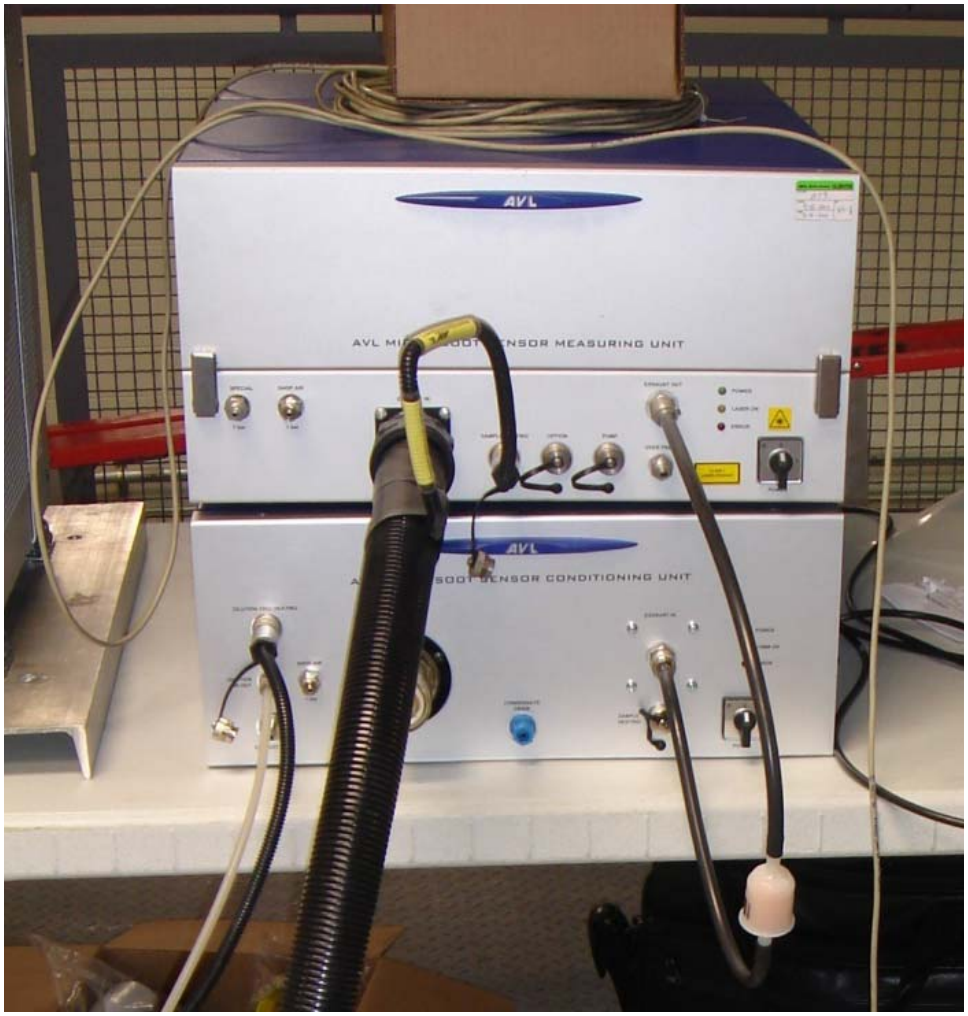
AVL 483 Micro-Soot Sensor (MSS) photoacoustic analyzer





Note that Conditioning Unit and heated line/diluter are not being used

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Apparatus for methods validation

- Low speed flow tunnel (one pass, unheated)
- Mini-CAST burner (black carbon aerosol generator)
- Catalytic stripper (to remove volatile PM)
- ~ 1.7μm cut-point cyclone pre-separator (to eliminate large agglomerates shed from walls)
- Sample splitters
- Sampling trains for Teflon and quartz filters
- LII 300, SuperMAAP, and AVL MSS

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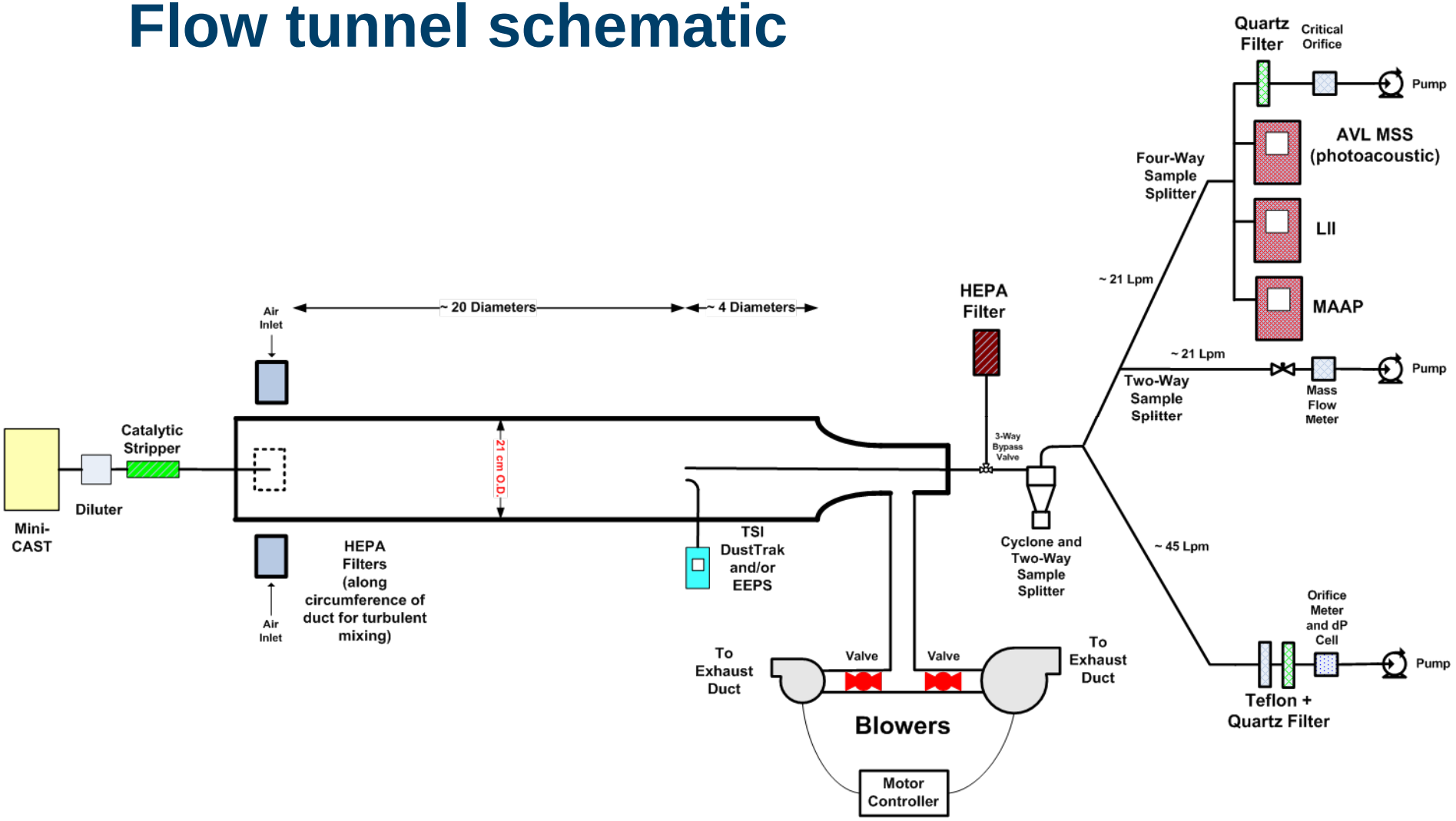
Flow tunnel schematic



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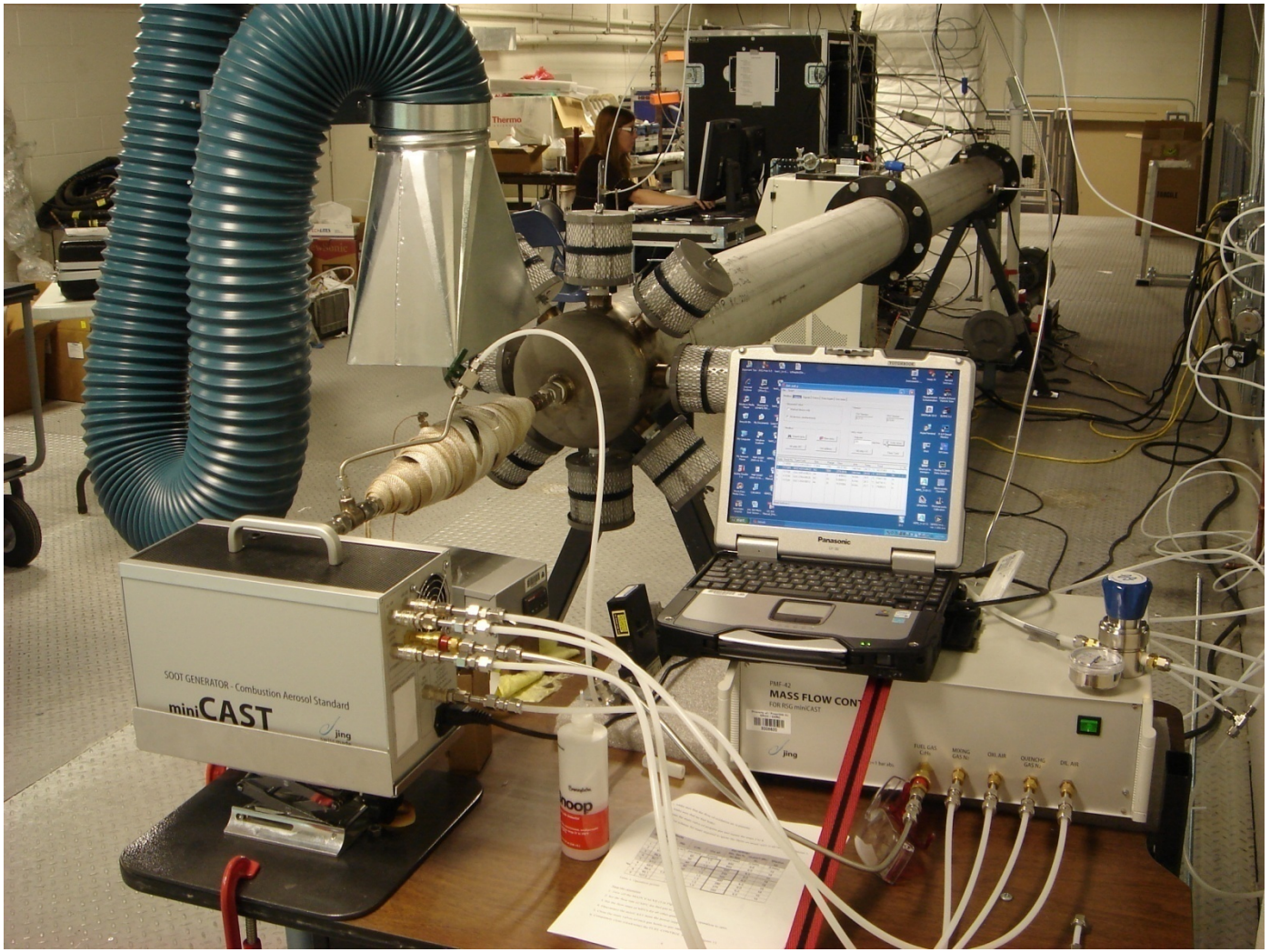
Aerosol generator and catalytic stripper



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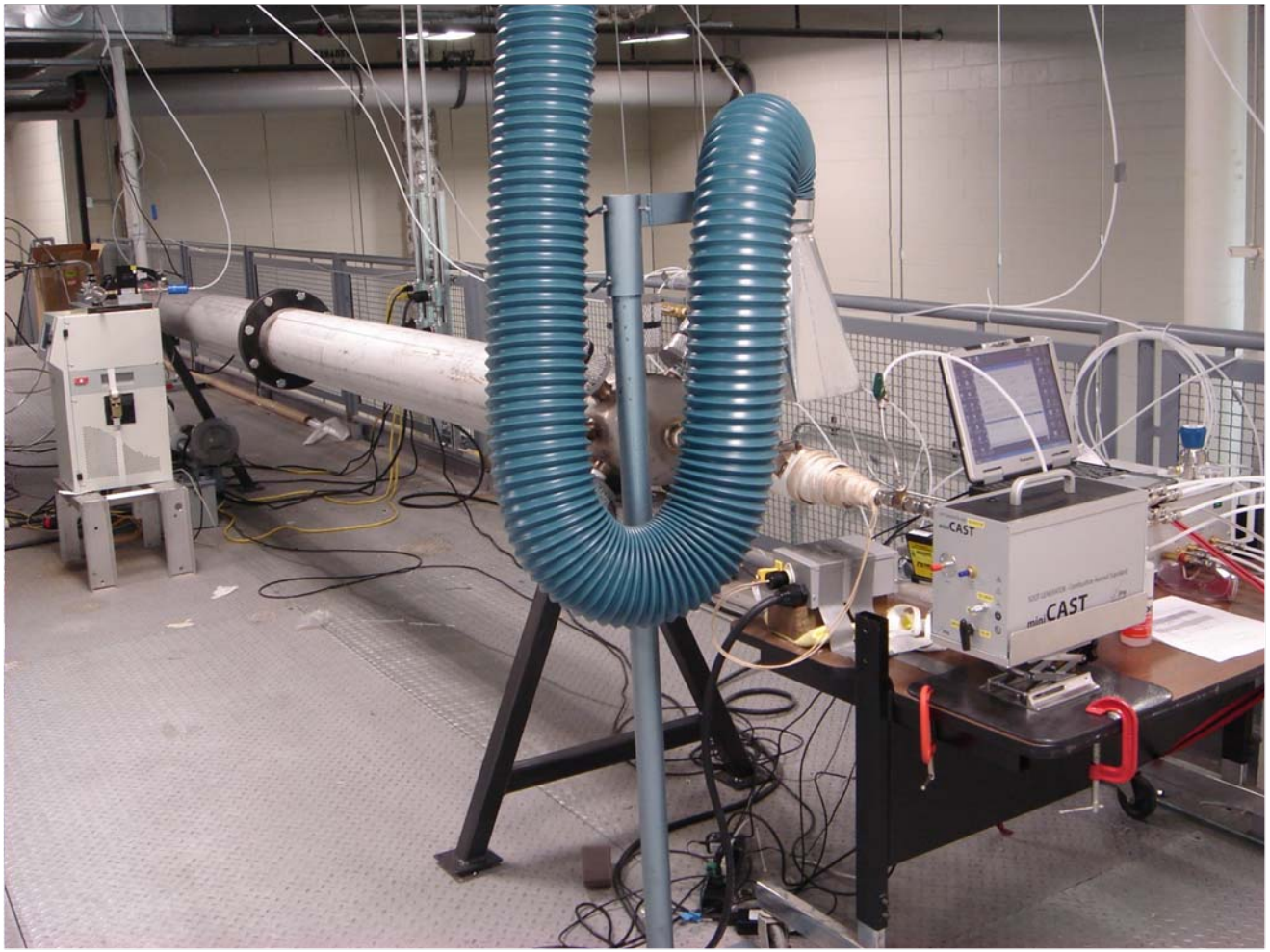
Flow tunnel and Engine Exhaust Particle Sizer (EEPS)



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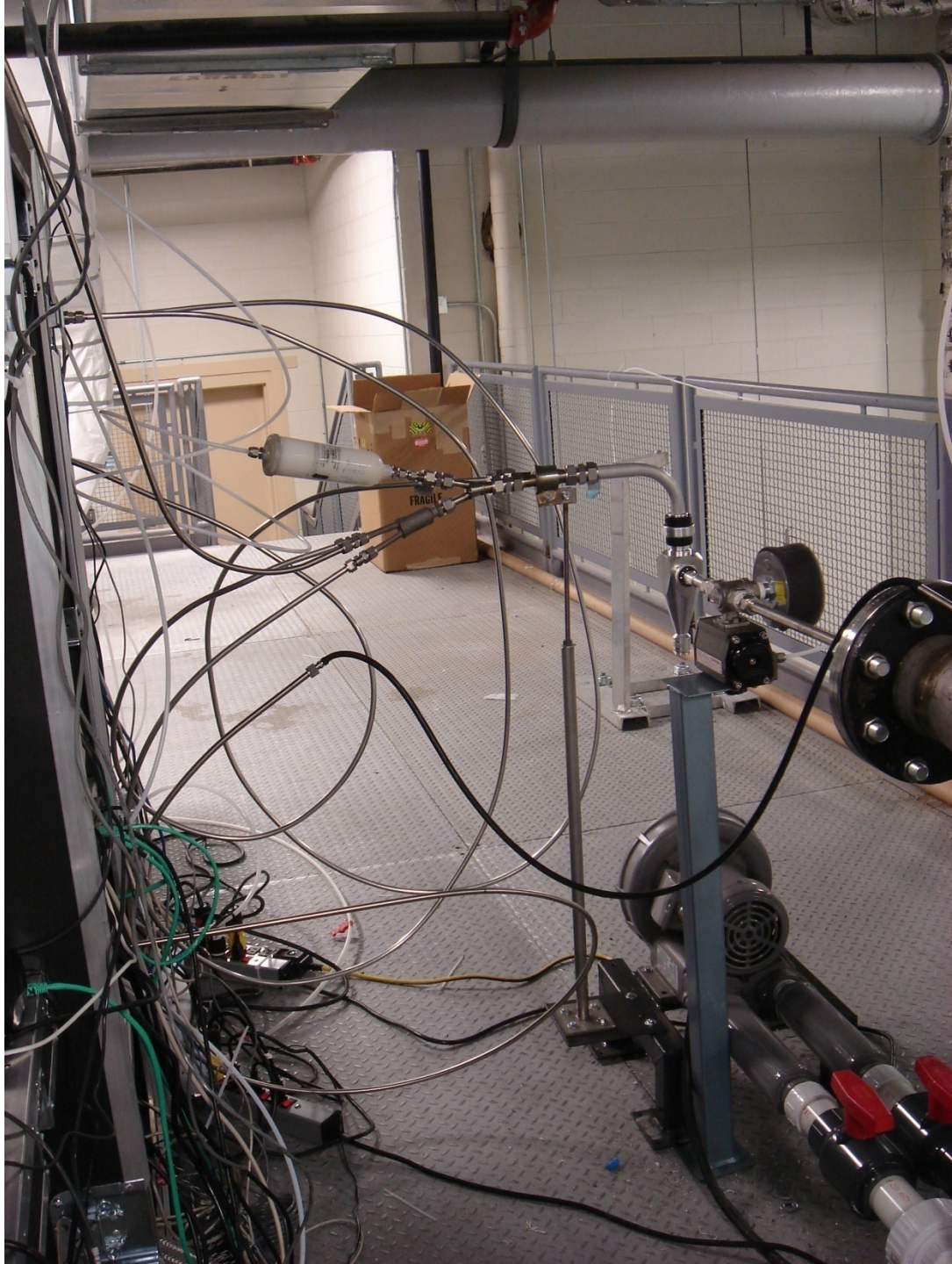
Sample distribution system



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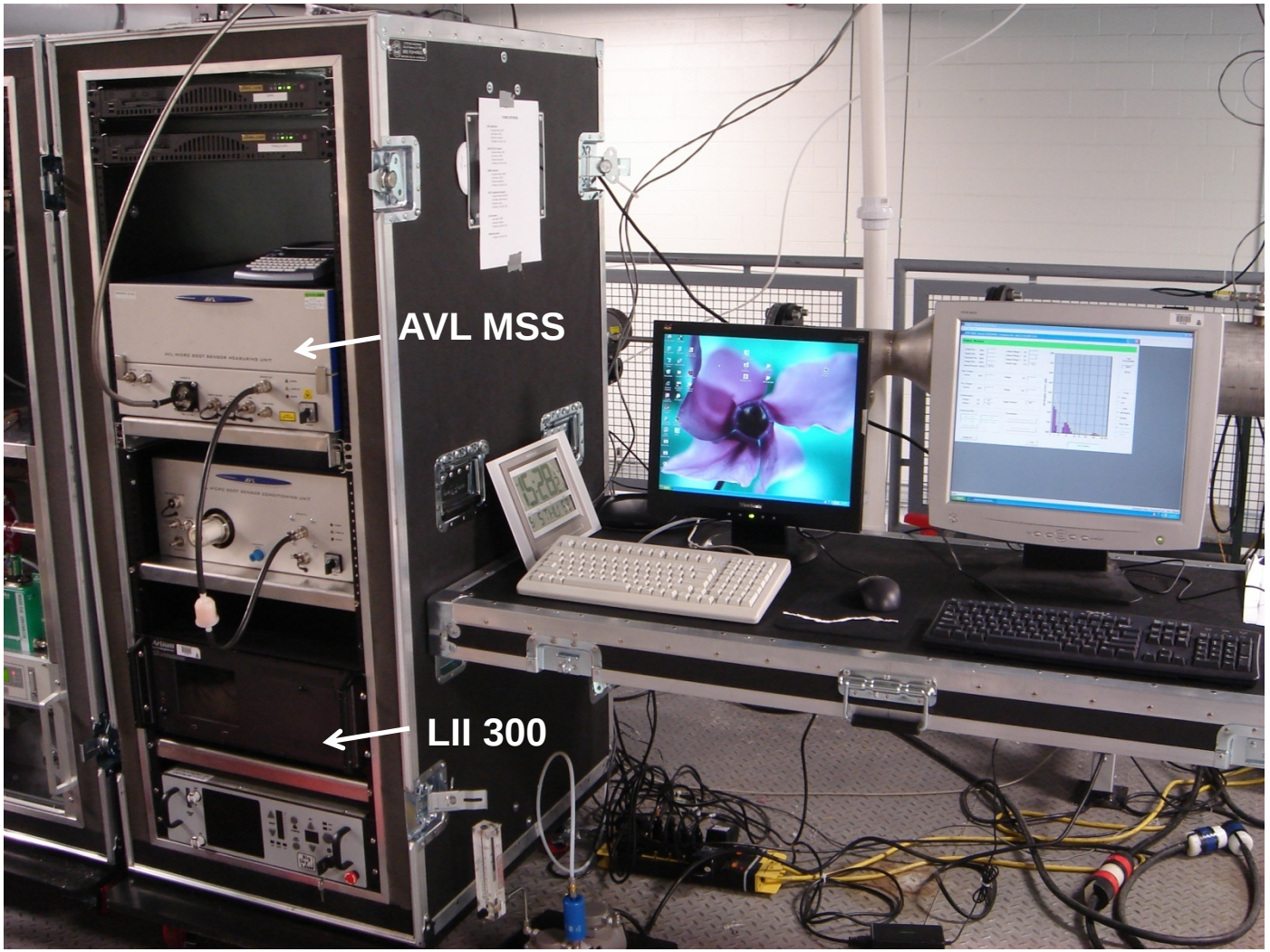
Right instrument rack and operator's station



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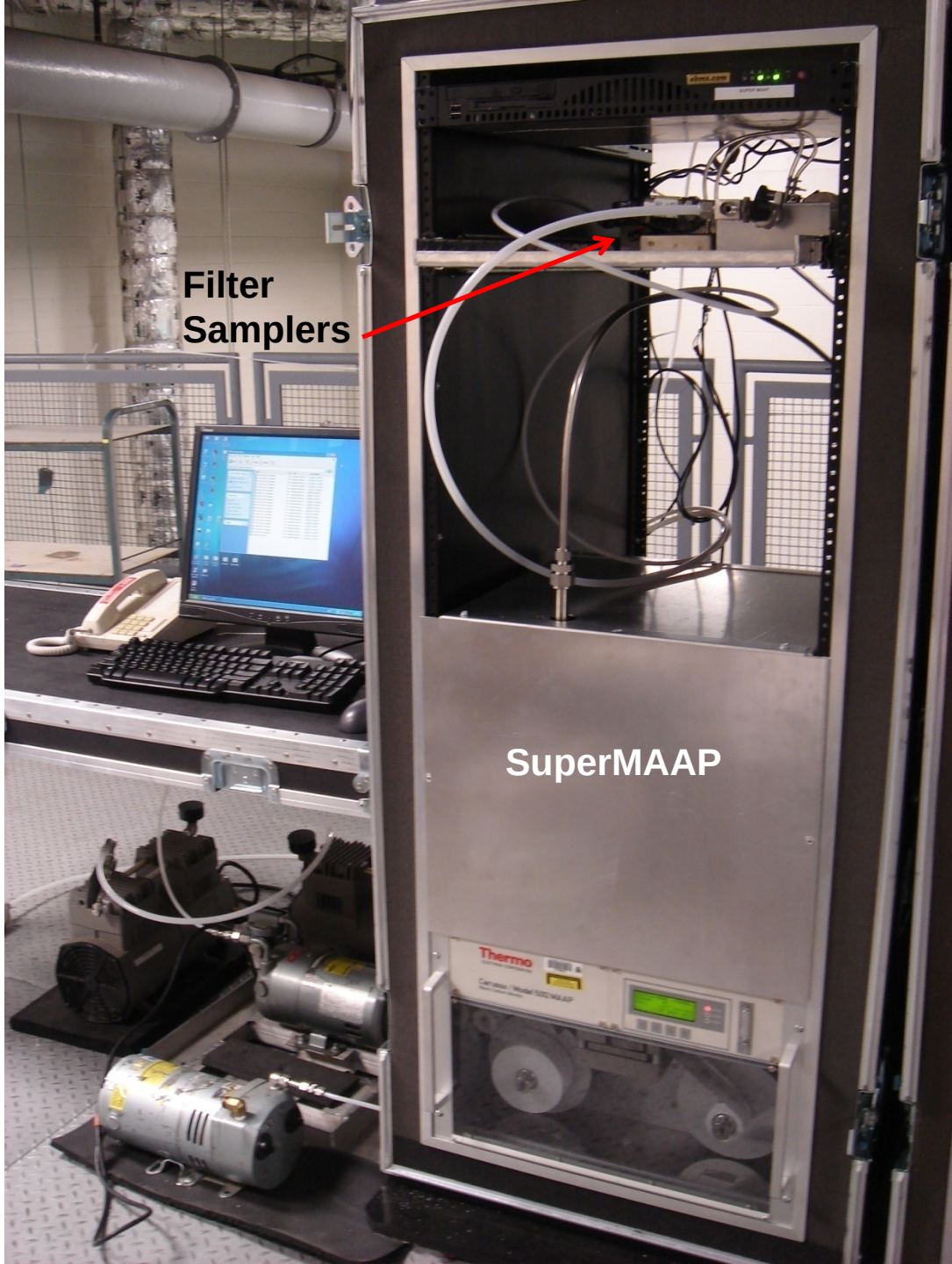
Left instrument rack and operator's station



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Typical tunnel velocity and concentration profile

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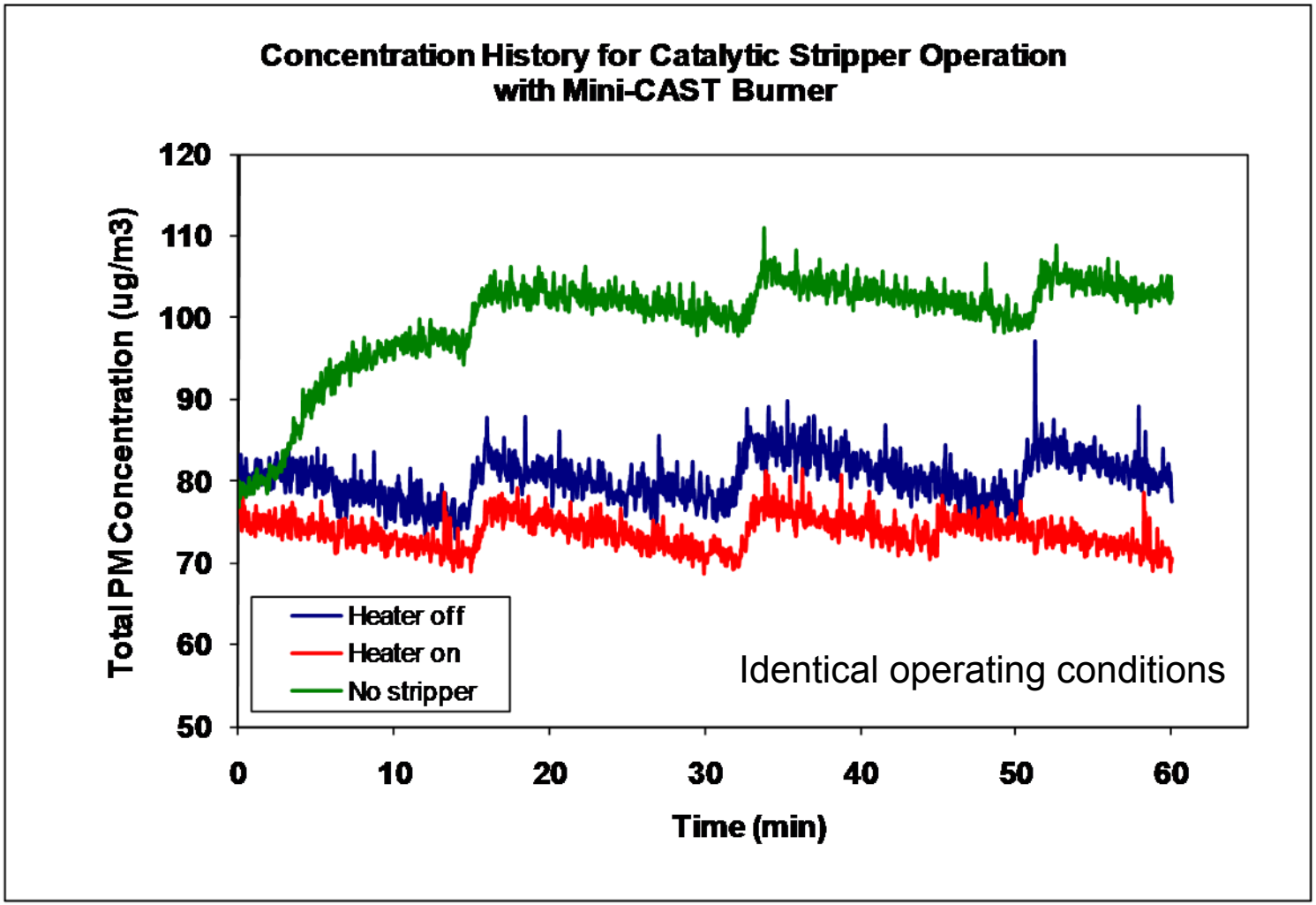
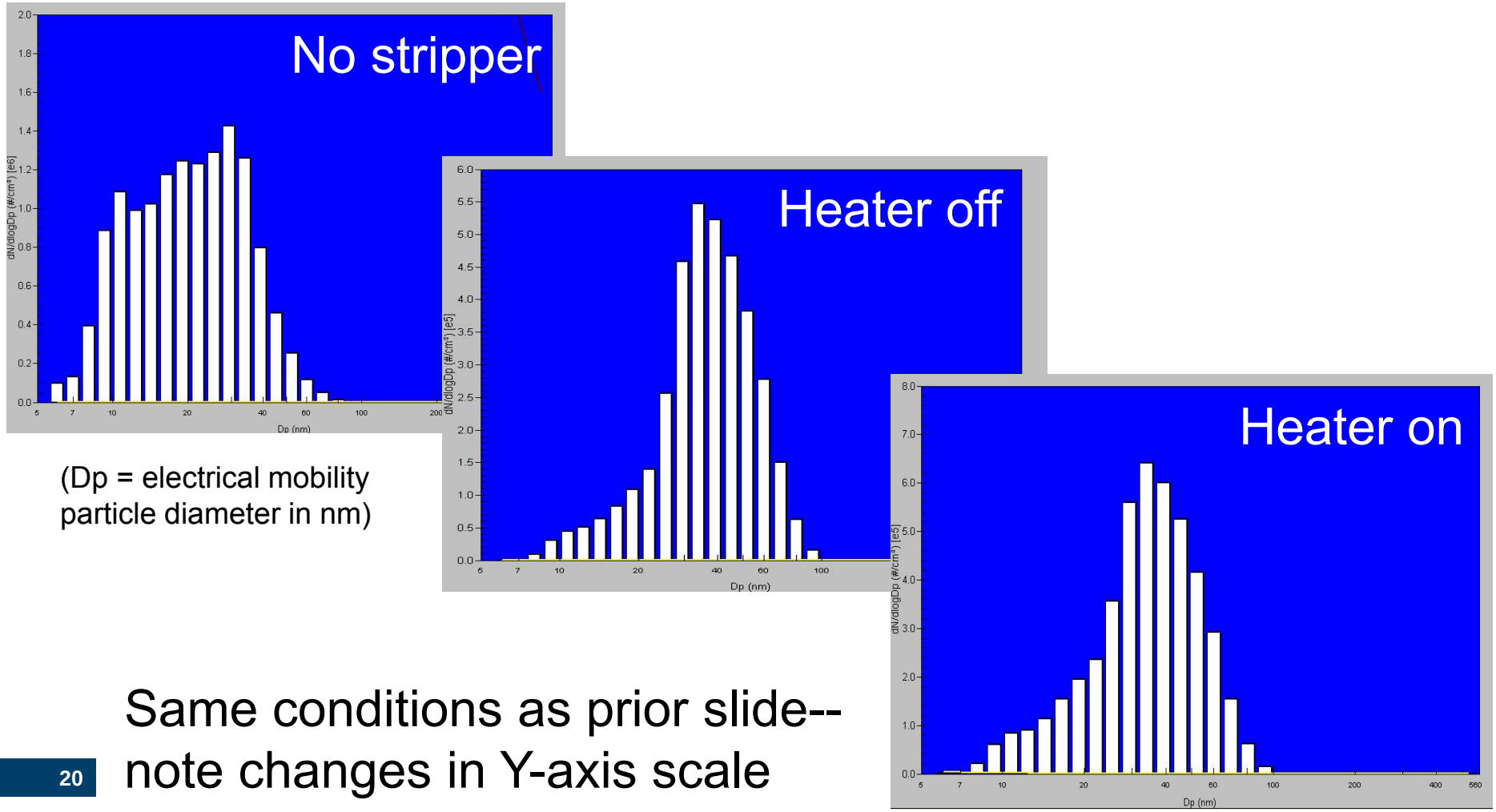
Typical CAST mass concentration output from EEPS instrument



Typical CAST differential number particle size distributions



(Dp = electrical mobility particle diameter in nm)

Same conditions as prior slide--note changes in Y-axis scale

Experimental matrix

Aerosol Type[a]	Sampling Condition	Target Soot Concentration (µg/m^3)	No. of Runs	Teflon Filter	Quartz Filter	MAAP	LII	* AVL MSS
Non-volatile PM	1	10	6	X	X	X	X	X
	2	50	6	X	X	X	X	X
	3	100	6	X	X	X	X	X
	4[b]	500	6	X	X	X	X	X
	5	1000	6	X	X	X	X	X
Total PM[b]	1	10	6	X	X	X	X	X
	2	50	6	X	X	X	X	X
	3	100	6	X	X	X	X	X
	4[c]	500	6	X	X	X	X	X
	5	1000	6	X	X	X	X	X

[a] Non-volatile PM = Mini-CAST® with catalytic stripper; Total PM = Mini-CAST without catalytic stripper (will include volatile organics).

[b] Conducted only if time and resources permit.

[c] Lowest priority tests.

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Current program status

- LII and MAAP instrument workshops were held at EPA
- SOPs have been developed for all methods and instruments which are currently undergoing EPA Quality Assurance review
- Flow tunnel and associated apparatus has been completed and all instruments and sensors have now been calibrated by the APPCD Metrology Laboratory
- All modifications have now been completed for the SuperMAAP and its performance exceeds all expectations
- Operational data have been collected on the flow tunnel and the Mini-CAST burner both with and without the catalytic stripper
- Two preliminary tests were conducted with all instruments except the LII which malfunctioned and is currently undergoing repairs

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Tentative work schedule

Activity	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2012 Jan	Feb	Mar
Conduct Non-Volatile PM Tests	■	■	■							
Conduct Total PM Tests			■	■	■	■				
Data Reduction/Lab Analyses	■	■	■	■	■	■				
Draft Report Preparation						■	■	■		
Final Report Preparation										■