AAFEX-II Mission Summary – 05 April 2011

AAFEX-II was by all accounts a highly successful mission as all objectives were achieved safely and without significant problems or delays. The paragraphs below provide a few summary comments regarding the mission, and its accomplishments and shortcomings.

Test Period: March 31 – April 3; note tests were finished several days earlier than planned because of the heroic efforts put forth by AEDC and MS&T in getting the complex sampling apparatus assembled, wired and plumbed; the superb aircraft operation and maintenance provided by DFRC (Figure 1); excellent engine performance and reliability (Figure 2); and generally cooperative meteorological conditions.

Engine Runs: As shown in Table 1, 11 separate emission tests were conducted, encompassing about 30 hours of engine run time. Although engine #3 suffered a compressor stall during Test Run 1 on March 26, both inboard engines performed flawlessly thereafter.

Test Participation: About 70 individuals from 20 institutions took part, either as experimenters, support crew or observers. Included were AEDC (Figure 3), AESO (Figure 4), Aerodyne (Figure 5), AFRL (Figure 6), MS&T (Figure 7), NASA LaRC (Figure 8), NASA DFRC, HQ, and GRC (Figures 9 and 10), Penn State (Figure 11) and E-31 team (Figures 12 and 13) members from UTRC, Boeing, GEAE, Honeywell, Pratt and Whitney, Rolls Royce, AVL, Transport Canada, National Research Council Canada, Artium, AVL, and TSI.

Report Card: Here's how we did in addressing the primary mission objectives.

1) <u>Evaluate alt fuel effects on engine performance and fuel-handling equipment (A)</u>

Because the DC-8 is not equipped with digital avionics, this goal was addressed by observing whether the fuels caused fuel system problems or negatively impacted engine power (i.e.., Donny to Scott: "Does #3 sound like it's running rough to you, Scott?") About half-way through the planned engine runs, however, ground-crew member Leo noted the aircraft flight management system displayed a digital fuel flow reading; having precise values for this parameter will greatly increase our ability to evaluate changes in engine efficiency and emissions performance compared to analyses done with needle gauge reading in AAFEX-I. In addition, procedures were adopted which minimized fuel system exposure to pure alternative fuels, so seal leaks did not pose a problem during the mission.

2) <u>Determine the effects of alt fuels on engine PM and gas phase emissions (A)</u>

The test plan called for characterizing #3 engine emissions as a function of power for five different fuels: pure JP-8, pure HRJ, 50:50 JP-8/HRJ blend, Sasol FT, and Sasol FT with sulfur additive. As show in Table 1, all these fuels were tested as planned. In addition, a third HRJ test was added and three of the fuels were burned in engines #2 and #3 simultaneously, which presented the opportunity to evaluate differences in emissions between the engines. As described in previous notes and shown in Figure 14, clear differences were seen between the fuels, with HRJ and FT fuels reducing PM emissions by 1 to 2 orders of magnitude at low engine powers.

3) <u>Investigate exhaust plume chemistry, including the role of fuel sulfur in regulating volatile aerosol formation in engine exhaust plumes (A-)</u>. Downwind observations were made during all tests, but at times ambient winds were either too low or from the wrong direction to advect plumes

toward the 143-m trailers (Figures 15 and 16). However, 30-m measurements from the main nearfield-sampling groups (AESO, MS&T, LaRC, ARI and AFRL) and ARI Mobile Laboratory (Figure 17) were of excellent quality and reveal volatile PM number and mass emissions are highly dependent on fuel sulfur and change significantly with ambient temperature and plume age. Data obtained during the highly successful, fuel sulfur test (Figure 18) will be particularly valuable in validating microphysical models of sulfate aerosol formation and growth.

4) Examine the effects of sample line chemistry and particle losses on emission measurements (B+). AESO (Figure 4) made a heroic effort to place three sets of identical instruments near the engine, 30-m downstream in the Deathbox, and within their trailer to assess effects of sampling lines on PM number and size. Although much data was obtained, instruments within the 30-m enclosure (DB2.0) performed poorly due to overheating from exposure to hot engine exhaust flow. However, the AAFEX-2 team performed extensive sample line characterization studies (Figure 19) before and after the engine runs, which will answer many questions about transmission loss as a function of size and how this changes as the lines become contaminated from use.

5) Conduct tests to support SAE E-31 development of standard exhaust sampling methods (A+). Considering serious planning only got underway two weeks before deployment, the E-31 piggyback test effort was a rousing success. With very limited resources, Dave, John, Robert and crew (Figure 12) were able to coral instruments, rakes, and plumbing components in short order and collect many hours of meaningful data to assess sampling system flows, pressures, transport efficiency, ease of use, reliability, etc. PM number and mass data were also recorded and should help guide refinement of ARP's being written for measurements of these parameters.

Proposed Post-mission Activities:

- Late April
  - Establish pass-worded FTP site for data exchange and archiving
  - Place Met data on FTP site
  - Start/Stop times + uncorrected fuel flows for engine runs placed on FTP site
  - Short summary presentation completed and sent to NASA project sponsors
- Early May: Telecon to discuss data exchange, archiving and reporting schedules.
- Mid May: Public presentation of preliminary results at FAA Roadmap meeting in DC
- Late August: Science team meeting in Hampton to present results and lay out report appendices
- Possible presentation of results at AGU or other fall meeting.
- January 2012: Submit draft reports
- March 2012: AAFEX-2 report complete

Table 1. Summary of Test Runs

Test Number	Test Date	Times		Test Duration	Engine Fuel		Objective
		Start	End		Left	Right	
1	26-Mar	1420	1530	1.1	JP-8	JP-8	Shakedown
2	28-Mar	0630	1040	4.1	JP-8	JP-8	Mapping + JP-8 Characterization-Cold
3	28-Mar	1300	1507	2.1	JP-8	JP-8	JP-8 Characterization-Warm
4	29-Mar	0605	0840	2.5	JP-8	HRJ	HRJ Characterization-Cold
5	29-Mar	1004	1225	2.4	JP-8	HRJ	HRJ Characterization
6	29-Mar	1331	1550	2.4	JP-8	HRJ	HRJ Characterization-Warm
7	30-Mar	0605	0910	3.1	JP-8	FT	Fuel S--FT Characterization- Cold
8	30-Mar	1045	1250	2.1	JP-8	Blend	HRJ/JP-8 Blend Characterization
9	31-Mar	0555	0850	3	JP-8/FT+S	FT+S	Fuel S--FT + S Characterization- Cold
10	31-Mar	1000	1330	3.5	Blend	Blend	HRJ/JP-8 Blend Characterization/E-31
11	1-Apr	1030	1445	4	JP8 & Blend	JP8 & Blend	JP-8 Characterization/E-31 Tests

Figure 1. The venerable DC-8 ground crew featuring (from left) Joe, mission MVP Donny, Leo, Scott, and Jose.

Figure 2. The star of our show, DC-8 CFM56-2C engine #3 shows stains from ingesting thousand of small insects during 30 hours of operation. Indeed, all the downstream inlets, sampling lines and instrument shelters were pasted with remains of insects who took their final, thrilling flights at speeds approaching mach 1, embedded within aircraft engine exhaust/fan flow.

Figure 3. AAFEX-II project engineer Robert and the extraordinarily talented AEDC mechanical/techical crew (clockwise from top) including Roy, Gary, Brad and Steve. Absent member Katie is shown in Figure 7.

Figure 4. AESO crew Arnel, Tuong and Xu, who is answering the question of how many of the group's 10 instruments survived 30 hours of engine runs in the 30-m Deathbox. Not shown: Triet.

Figure 5. Team Aerodyne with Eben (MIT), Berk (MSU), Ed, Scott, Jon, Zhenhong, Rick and Mike. In case you're wondering, the Mobile Lab crew breathes medical oxygen when sampling near-field exhaust plumes.

Figure 6. The highly efficient and experienced AFRL team including Dave, Joe, Chris, Matt and Edwin. The group disassembled their test apparatus, packed their equipment and was on the road within 3 hours after the final engine run.

Figure 7. Fashionably-dressed Phil (top) poses with the hard-working MS&T crew, which includes Max and Prem (seated), plus (from left) Steve, Brian, Jonathan, Don, Emit, and Veronica. Not shown: Dave.

Figure 8. The homeless Langley Aerosol Research GroupE (LARGE) loads the borrowed EM-50 RV for the trip to Palmdale. From left: Bruce, Eddie, Andreas, Lee, Ricky Bobby, Luke and Charlie.

Figure 9. Frank Cutler (DFRC), Jay Dryer (NASA HQ) and Dan Bulzan provided support and needed adult supervision to the AAFEX-II project.

Figure 10. Changlie (NASA GRC) installing his instruments in the back of the AEDC trailer, which was also home to the Penn State soot sampling group shown in Figure 11.

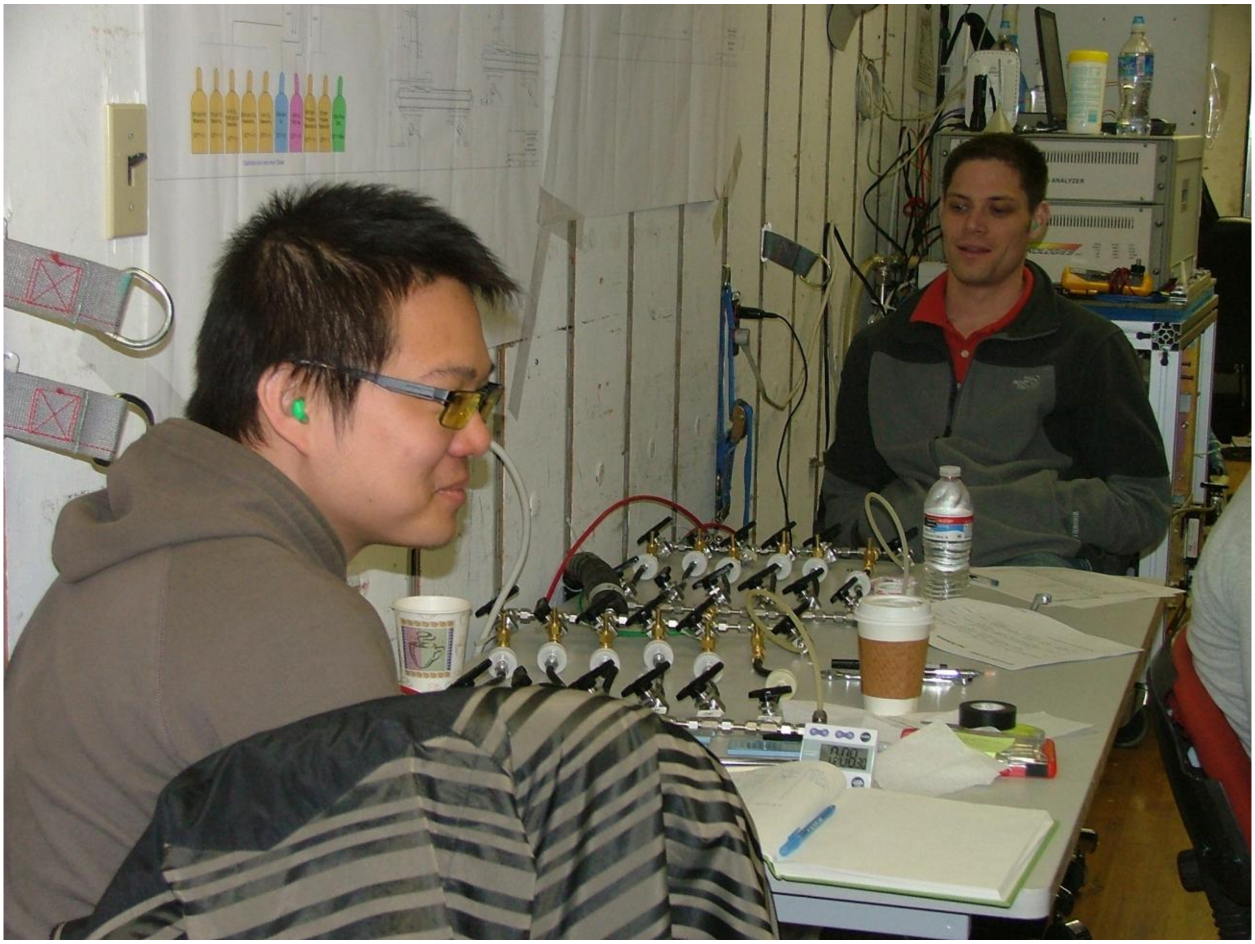

Figure 11. Chung (PSU) and Chris (NASA GRC) pose with their soot-sample collection apparatus.

Figure 12. E-31 contributors pose with project scientist Bruce (center). Around the horn from left: Robert, Russ, team-lead Dave, John, Mark, Greg, Don, Anuj, Katie, and Brad. The E-31 trailer crew changed on daily basis, possibly because of the debilitating effects of prolonged attempts at making precise PM measurements (see Figure 8)

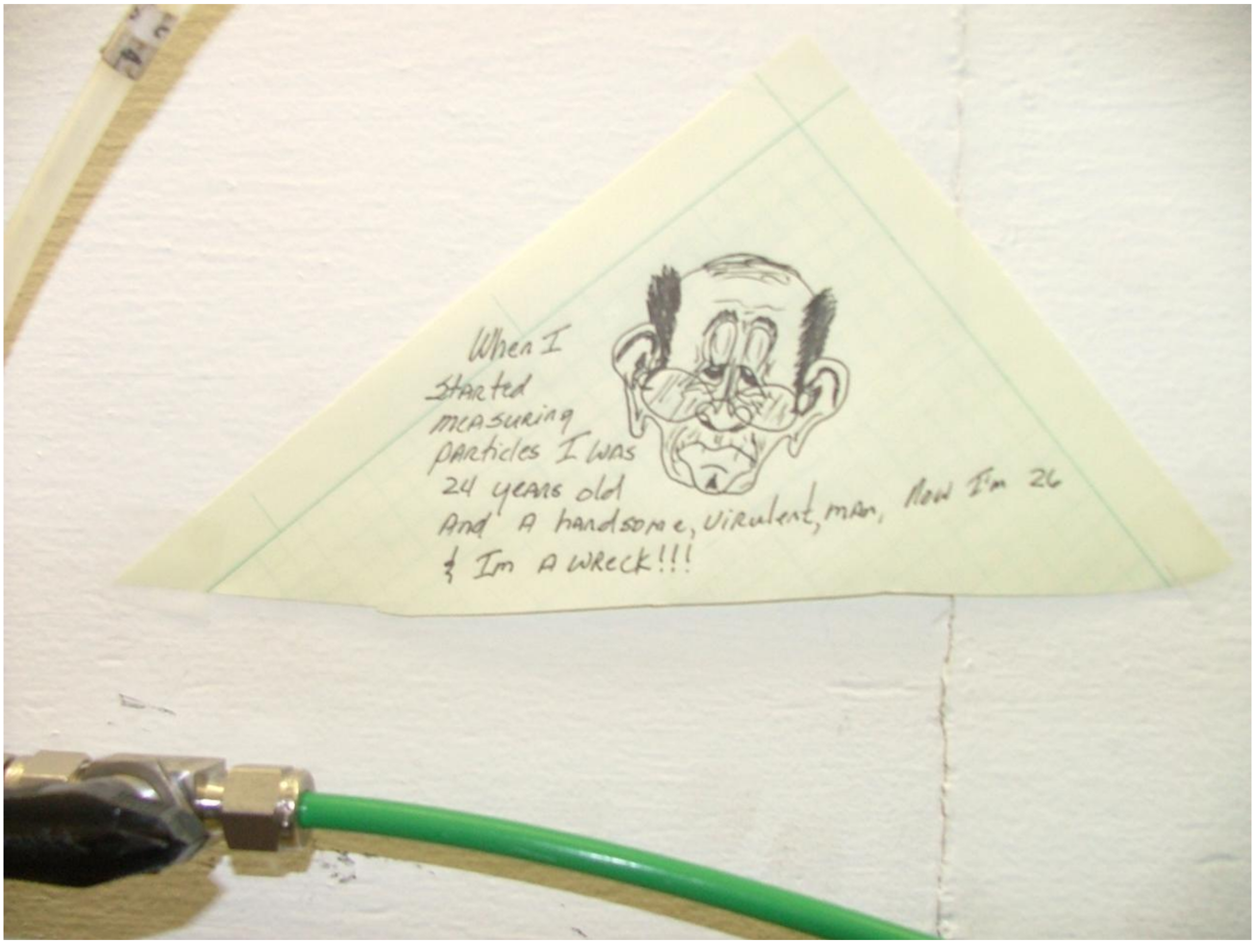

Figure 13. Artwork featured in E-31 trailer providing one of the reasons why having an ARP on PM sampling and measurements in place by December is such a challenging task.

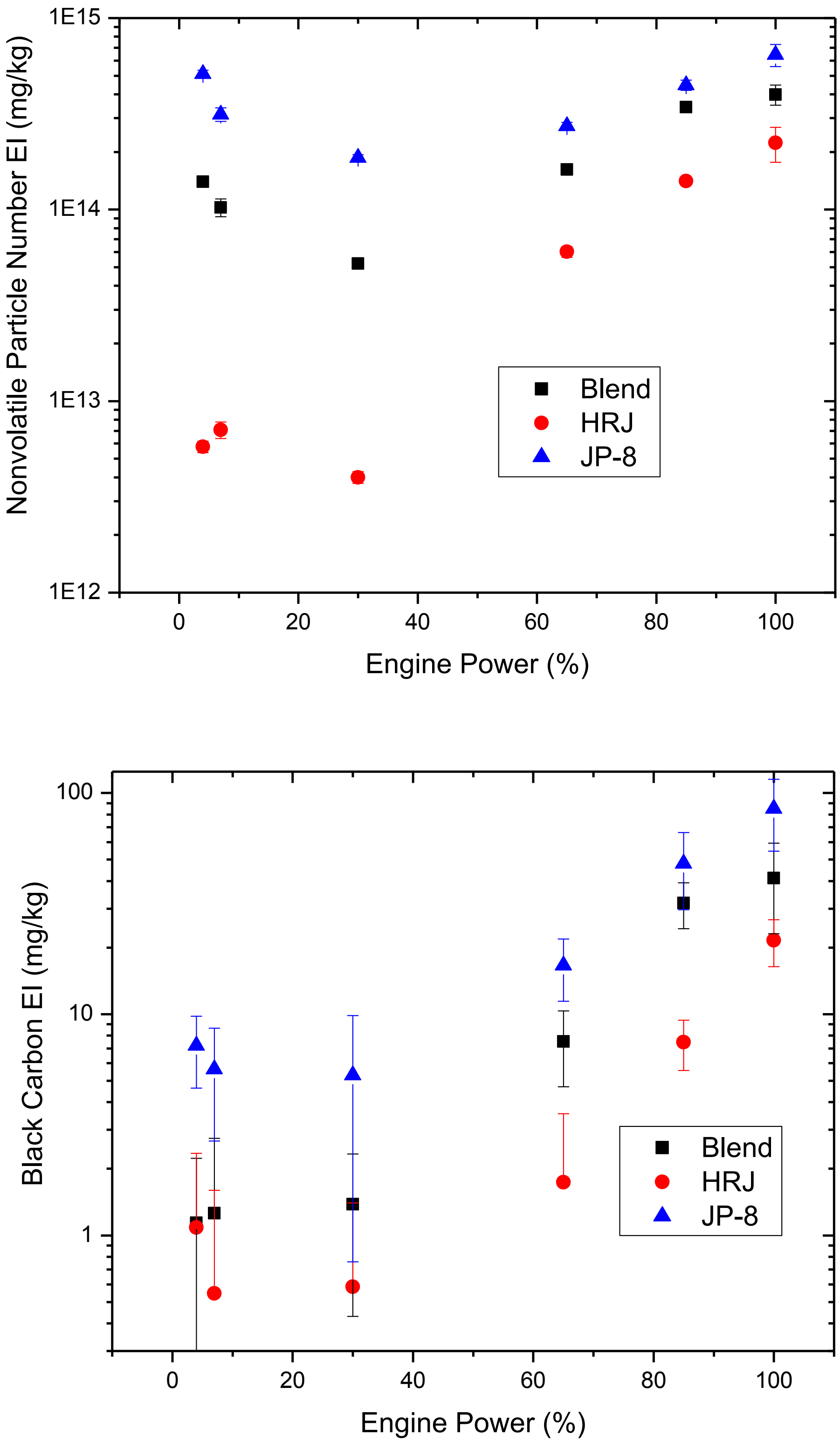

Figure 14. Preliminary comparison of nonvolatile particle number (top) and mass emission indices measured at 1-m behind the right inboard engine for pure HRJ, pure JP-8 and a 50:50 mixture of the two fuels.

Figure 15. AAFEX-II cutest-couple Max and Veronica manning (so to speak) the MS&T downstream sampling trailer.

Figure 16. Luke, Eben and Jon beside their windowless home, the ARI/NASA 143-m instrument trailer.

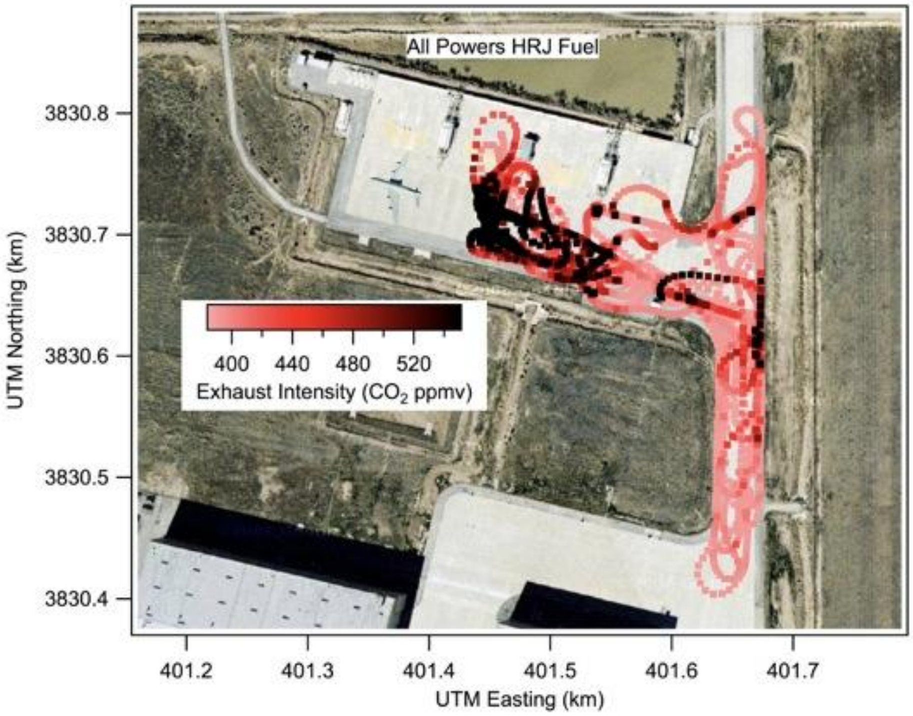

Figure 17. Track plot of CO_2 measured from the Aerodyne Mobile laboratory during typical, downwind exhaust plume sampling runs. The lab was equipped with an extensive suite of gas and aerosol sensors that should yield an unprecedented wealth of data to elucidate the plume aging process.

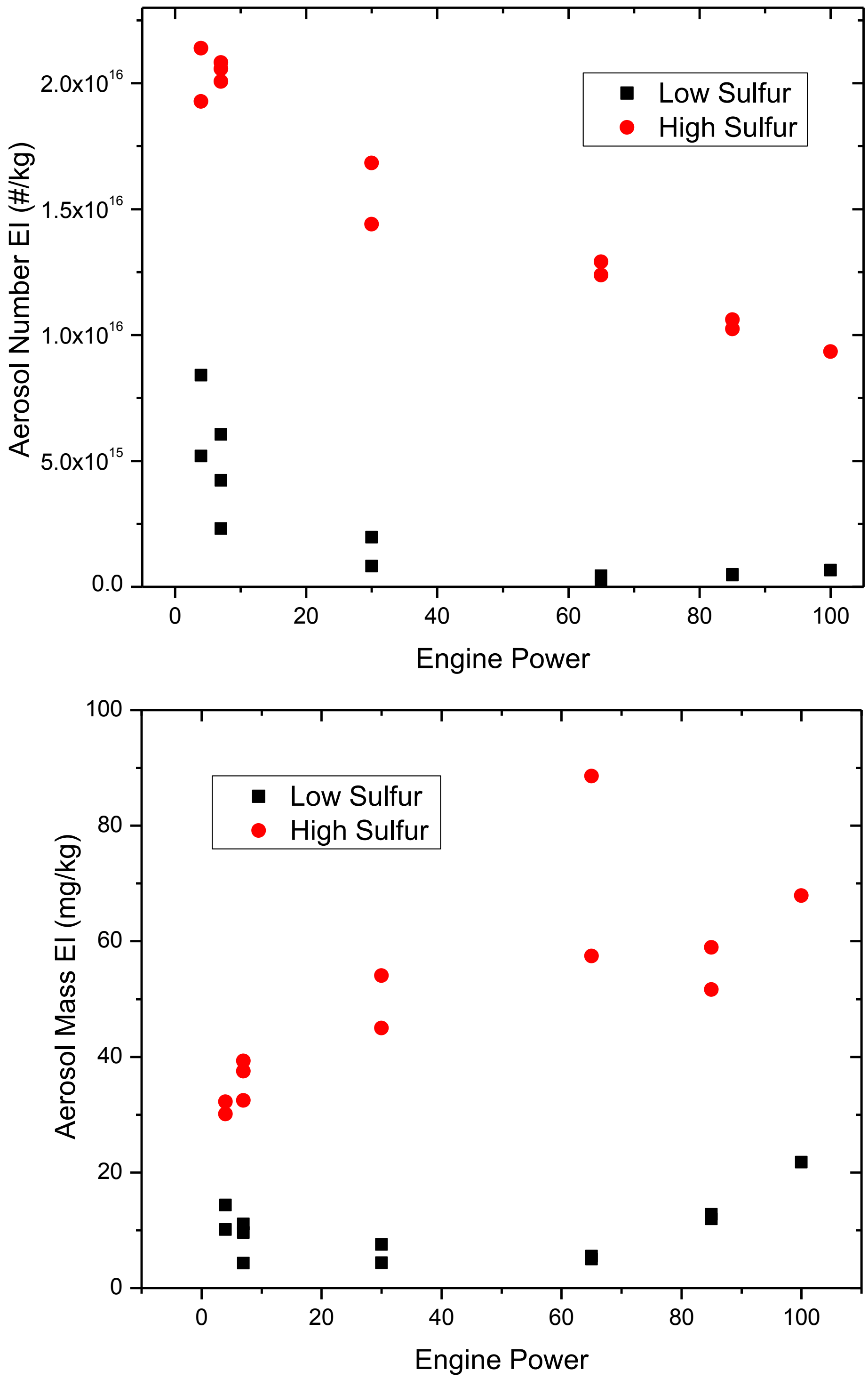

Figure 18. Aerosol number (top) and mass (bottom) emission indices from samples collected 30-m behind the #3 engine as it was burning standard FT fuel and the FT fuel plus tetrahydrothiophene (1000 ppm S) additive illustrating the impact of sulfur on volatile aerosol formation.

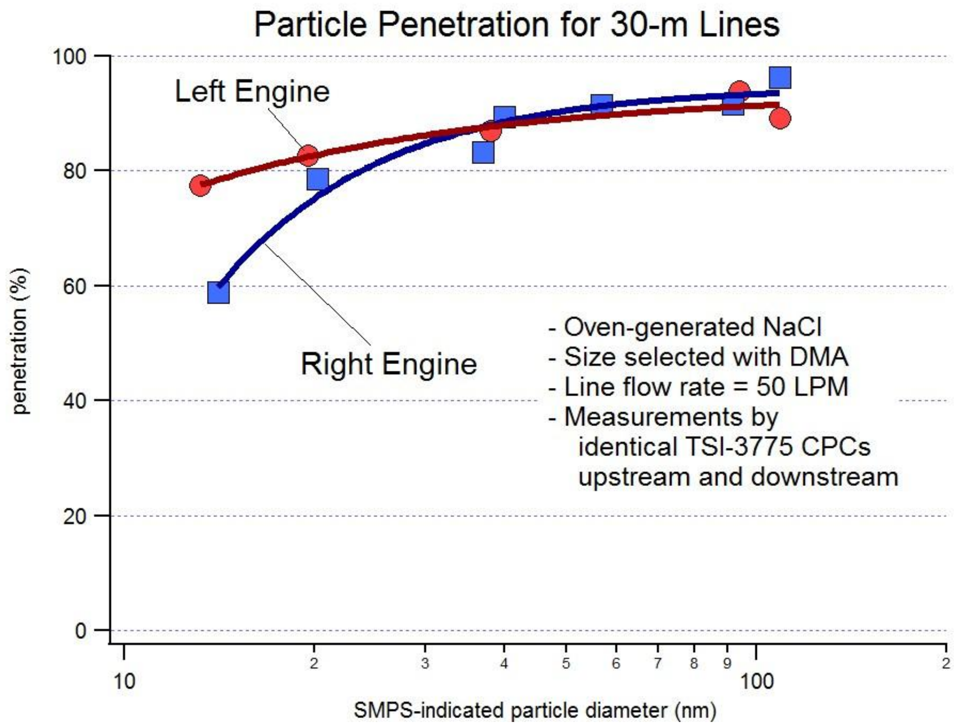

Figure 19. Preliminary plot of particle transmission efficiencies for the two, 30-m sample lines. The tests were repeated after the engine runs to determine how the efficiencies changed with use.