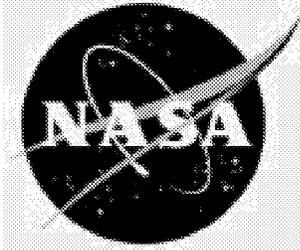NASA/TM-2001-211226

NASA's Atmospheric Effects of Aviation Project

Results of the August 1999 Aerosol Measurement Intercomparison Workshop, T-38 Aircraft Sampling Phase

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October 2001

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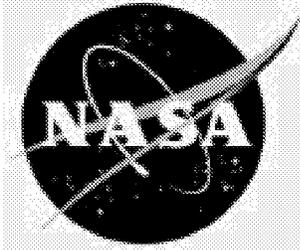
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Contents

Nomenclature

AEAP	Atmospheric Effects of Aviation Project
CNC	condensation nuclei counter
CPC	condensation particle counter
DMA	differential mobility analyzer
EAC	electrostatic aerosol classifiers
EI	emission index
EP	engine power
GMD	geometric mean diameter
GRC	John H. Glenn Research Center
LaRC	Langley Research Center
LPC	laser particle counter
MASS	Mobile Aerosol Sampling System
NDIR	nondispersive infrared
nASA	nanometer aerosol size analyzer
PAGEMS	Particulate and Gaseous Emissions Measurement System
PNC	particle number concentrations
PSL	Particle Simulation Laboratory
SASS	Subsonic Assessment Program
SMPS	scanning mobility particle sizer
UMN	University of Minnesota
UMR	University of Missouri-Rolla

1. Introduction

Because commercial aviation is anticipated to increase substantially in both volume and extent during the next two decades (Boeing 1996; Baughcum, Sutkus, and Henderson 1998) and aircraft represent a unique source of anthropogenic emissions (inasmuch as they are routinely emitted above the boundary layer), the need to better understand their environmental impact is clear. NASA's Atmospheric Effects of Aviation Project (AEAP) addresses this need. A major component of the AEAP—the Subsonic Assessment Program (SASS)—was formed with the goal of characterizing the effects that the current fleet of commercial aircraft have on atmospheric chemical and radiative processes, and what effect they may have in the coming years, as air traffic increases (Friedl 1997). Aircraft are prolific sources of both soot and sulfate particles to the upper troposphere and lower stratosphere (Fahey, Keim, and Chan 1995; Anderson, Cofer, and Brunke 1998; Anderson, Cofer, and Hudgins 1998; Miake-Lye et al. 1998; Karcher and Fahey 1997). These particles may have an impact upon climate through direct absorption/reflectance of solar radiation (Pueschel et al. 1992); by altering cirrus cloud formation, reflectance, or duration; or by providing additional surface area upon which heterogeneous chemical processes, such as ozone destruction, can occur. Because of their potential to perturb these important atmospheric processes, the AEAP has placed a high priority upon gaining an increased understanding of particle formation and growth processes within aircraft plumes and upon characterizing the particulate emissions of turbine engines (Friedl 1997).

To accurately assess the atmospheric effects of aircraft-generated particulates as well as to develop and test predictive models for aircraft emissions, the number density, size, and composition of aerosols within engine exhaust and aging plumes must be understood and well characterized. Thus, the AEAP has funded several individual groups to make observations within a number of different measurement venues including behind aircraft in-flight, parked in run-up areas, as well as downstream of turbine engines mounted in test cells. Because the soot and sulfate particles within fresh plumes typically range from a few to a few tens of nanometers in diameter, measurement approaches are very limited. Butanol-based condensation nuclei counters (CNCs) have been used in most aircraft emission studies (e.g., Hagen et al. 1998; Anderson, Cofer, and Brunke 1998; Anderson, Cofer, and Hudgins 1998; Fahey, Keim, and Chan 1995; Twohy, Gandrud, and Weinheimer 1998). Size distributions are obtained either by using an electrostatic differential mobility analyzer coupled to a CNC (Hagen et al. 1998) or a battery of CNCs with different lower size cutoffs (Anderson, Cofer, and Brunke 1998; Anderson, Cofer, and Hudgins 1998; Cofer, Anderson, and Bagwell 1998; Brock et al. 2000). For composition information, samples are typically delivered to a pair of identical CNCs, one with an unheated inlet to monitor total particulate emissions and the other with a heated inlet to evaporate sulfate/water particles to determine the nonvolatile (or soot) particle fraction (e.g., Cofer, Anderson, and Bagwell 1998). Observations are reported in terms of emission indices (EIs) or the amount of pollutant generated per kilogram of fuel burned. This is most often determined by taking the ratio of the specific pollutant concentration to that of a conserved combustion tracer, such as CO_2. For aerosols, EIs are reported as the number of particles generated per kilogram of fuel burned. If size distribution measurements are also recorded, an inferred mass EI (grams per kilogram of fuel burned) can be estimated by multiplying the calculated aerosol volume times an assumed aerosol mass density. Gravimetric analysis of aircraft particulate emissions has not been successful because of the amount of exhaust gas volume required to obtain a measurable accumulation (weight) of particles on filtering mediums.

Aircraft aerosol EIs have been recorded by AEAP-sponsored investigators. For example, the University of Missouri-Rolla has reported measurements from behind aircraft operating in run-up areas (Whitefield and Hagen 1995), in-flight (Hagen, Trueblood, and Whitefield 1992; Hagen et al. 1998), and in test cells (Whitefield and Trueblood 1993; Wey et al. 1998). The University of Denver has obtained airborne observations in aged aircraft plumes (Fahey, Keim, and Chan 1995) as well as very

fresh exhaust emissions (Brock et al. 2000). The Langley Group has made near-field, airborne measurements behind a variety of aircraft (Anderson, Cofer, and Brunke 1998; Anderson, Cofer, and Hudgins 1998; Anderson, Cofer, and McDougal 1999) as well as recent determinations of EIs in decaying plumes over the North Atlantic (Anderson et al. 1999).

Unfortunately, a wide variation in aerosol emissions indices and chemical and physical properties has been reported in the exhausts of subsonic commercial aircraft. Because a significant fraction of these aerosol measurements has been measured by various independent research teams involved in the SASS studies, it became necessary to determine if differences in aerosol measurement system components and/or techniques used by these groups were responsible for the wide variation in particle concentrations and properties observed in commercial aircraft exhaust. Because the data have, for the most part, been collected with similar aerosol counters, it appeared doubtful that the discrepancies would be explained by instrumental differences alone. Other sources of differences between the observations may include sampling issues, plume age, engine type and condition, environmental conditions, and fuel sulfur content.

Thus, to evaluate instrumental error as a source of the observed discrepancies, an Aerosol Measurement Intercomparison Workshop was sponsored by NASA's AEAP/SASS Program. This workshop took place August 1–14, 1999, at the NASA Langley Research Center in Hampton, Virginia. The first week of the 2-week workshop was devoted to challenging the core detection elements of the aerosol measuring instruments with laboratory-generated aerosols. The second week was focused on testing the efficiency and sensitivity of the measurement systems by sampling the exhaust from an LaRC T-38 Talon aircraft. Invitations to the workshop were issued to all groups that participated as aerosol investigators in SASS-sponsored airborne and ground-based field experiments. The present report is intended to be a follow-on to the published results from the laboratory phase of the investigation (Cofer et al. 2001). This report summarizes the aerosol measurements made from sampling the exhaust from the LaRC T-38 Talon aircraft during engine run-ups on the tarmac and addresses some of the aspects of sampling probe design and protocols.

2. Participants, Instrumentation, and Affiliations

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2.2.2. Instrumentation

The ground-based aerosol measurement system (DMA) consists of an electrostatic classifier that separates aerosols in a sample stream into size ranges and is connected to a TSI Model 3025 Ultrafine Condensation Particle Counter that counts the particles. A computer controls the classifier voltage sweep, and particle counts are directed into inversion software that results in the generation of 25 size bins. Flows are controlled by mass flow controllers. The system determines an aerosol size distribution from 5 to 250 nm.

The LaRC airborne instrument suite was designed for use aboard an aircraft to provide continuous measurements of total and nonvolatile aerosol number densities with crude particle sizing. The system is composed of two ultrafine condensation nuclei counters (TSI Model 3025 CNCs) and two standard condensation nuclei counters (TSI Model 3760 CNCs). Both types of CNCs have ≈ 1 Hz response times and are butanol based. Some evidence of sensitivity of butanol-based CNCs to particle composition has been reported (Ball, Hanson, and McMurry 1999). Extensive laboratory characterizations and calibrations indicate the ultrafine and standard CNCs have 50 percent size cutoffs at ≈ 5 and 13 to 15 nm, respectively, when operated in the flight configuration. To prevent saturating these instruments in the highly concentrated aircraft exhaust plumes, sample air is withdrawn from a sampling manifold through a critical flow orifice and immediately diluted by a factor of 10 to 50 with a concentric flow of filtered cabin air. This process provides the secondary benefit of allowing the CNCs to be operated at constant sample pressure and volumetric flow. The instruments are arrayed so that one each of the ultrafine and standard CNCs share a common inlet which can deliver sample either at cabin temperature ($\approx 20°C$) or heated to 150° to 300°C by passage through a 15-cm heat-tape-wrapped tube. This arrangement allows quantification of total aerosols >5 and >15 nm along with the number of nonvolatile, presumably soot, particles and, by difference, volatile aerosols in the same size categories.

Supporting (for determination of aerosol EIs) measurements of carbon dioxide concentrations were determined with a LI-COR LI-6252 CO_2 Analyzer, which is a nondispersive infrared (NDIR) spectrometer. The system used infrared absorption of the 4.26-μm CO_2 absorption band. Water is an interference in this spectral region; therefore, the samples were N_2 dried (during dilution) before introduction into the LI-COR.

2.3. NASA Glenn Research Center Group

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2.3.2. Instrumentation

The GRC Particulate and Gaseous Emissions Measurement System (PAGEMS) extractively samples combustion gases from aircraft gas turbine combustors and engines. Differential mobility analyzers and condensation nuclei counters are used in tandem to characterize the emissions in terms of particulate total concentration, size distribution, and volatility. A suite of gas analysis equipment measures CO_2, NO_x, and SO_2 levels in the combustion gases. Data can be collected over a wide range of operating conditions, pressures up to 250 psig, particulates 10 to 500 nm in size, 10^4 to 10^{13} particles/cm^3, and gas species down to parts per million levels.

2.4. University of Missouri-Rolla Group

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2.4.2. Instrumentation

The Mobile Aerosol Sampling System (MASS) uses extractive sampling from an aerosol source and delivers the sample to various aerosol characterizing devices: particle (CN) counters, a laser particle counter (LPC), and one or more Electrostatic Aerosol Classifiers (EAC). The LPC is used for counting and sizing large particles by using optical techniques; the EAC is used to size particles at the small end of the size spectrum. A thermal discriminator can be used to remove volatile material from the particles before characterization. Our TSI Model 3025 Ultrafine CNC counts particles down to 3 nm in diameter. Holding tanks are used to capture airborne samples for quasi-real-time size distributions. Size distribution data can be acquired for particles in the diameter size range of 7 nm to 5 μm. Concentrations of total particles (CN), nonvolatile particles, and particles in specific size bands can be continuously measured. The system operation and data acquisition are computer supported.

Previously, the system has been deployed for airborne sampling missions on the NCAR Sabreliner, the DLR Dassault Falcon 20E, and the NASA DC-8 and for various ground-based field sampling projects, including the Glenn PSL and flametube facilities, USAF Phillips Laboratory, McDonnell Douglas, Air France, Pratt & Whitney, and Arnold Engineering and Development Center.

2.5. University of Minnesota Group

2.5.1. Participants

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2.5.2. Instrumentation

The UMN research instrumentation consisted of a nanometer aerosol size analyzer (nASA) that was capable of scanning 30 size channels between 3 and 100 nm in a total time of 3 sec. The analyzer includes a bipolar charger, an extended-length nanometer differential mobility analyzer, and an electrometer. This combination of components provides particle size spectra at a scan rate of 0.1 sec/channel. Particle concentrations were measured using a TSI Model 3025 Ultrafine Condensation Particle Counter. An additional TSI Scanning Mobility Particle Sizer (SMPS) was used during the laboratory phase of the polydispersed aerosol intercomparisons.

3. Field Tests

Tests were conducted sampling LaRC T-38-generated exhaust to evaluate the transfer efficiencies (particle losses) of the complete particle measuring systems of each participating group, assembled in their typical configuration for sampling aircraft exhaust. Exhaust from the port engine (J85-GE-5H) of the LaRC T-38 was sampled at power levels ranging from 48 percent (idle) to 100 percent (full military power). Typically, the port engine was operated at a specified power for 5 min during which sampling was conducted. Initially, two sampling probes were tested. One was a water-cooled UMR probe used in many previous studies (Hagen, Trueblood, and Whitefield 1992; Whitefield and Trueblood 1993). Exhaust samples drawn through the UMR probe were always diluted by a factor of 7. This probe was tested in both the water-cooled and water-off modes. The other probe tested was a new LaRC high-temperature probe that was never cooled. It has a 0.03-in. orifice through which the sample was drawn in from the bulk probe flow. Most bulk flow was vented back to the outside air. Flow through the orifice occurred because the orifice was maintained at a pressure differential of 22 torr; that is, flow on the downstream side of the orifice (used to acquire our aerosol samples) was controlled at 22 torr lower than the main probe inner pressure. This condition resulted in a 2.5 L/min flow of exhaust mixing with our dry N_2 diluent at approximately 740 torr. Essentially two dilution factors were used with the LaRC probe samples during these tests, primarily dependent upon the probe distance from where the engine exhaust exited the turbine. Dilution factors during these tarmac tests for the LaRC probe were either ≈90:1 at 1 m or ≈30:1 at 9 m behind the engine. A diluted sample was then fed into a common distribution manifold where participating groups could simultaneously determine the aerosol concentrations and/or size distributions.

The UMN nASA (Han et al. 2000) actually performs better at high particle concentrations because it uses an electrometer rather than a condensation particle counter (CPC) for detection. As a consequence, the nASA, with exception to the probe evaluations, drew its samples from the LaRC high-temperature probe ahead of the 0.3-in. orifice and had a separate N_2 dilution system, typically using dilutions ranging from 2:1 to 5:1. Because of the unique speed with which the UMN nASA could sample the exhaust emissions (30 size channels ranging from 3 to 100 nm in 3 sec), UMN could switch quickly between sampling the UMR and LaRC probe during the dual probe evaluations. In that manner we were able to evaluate in-probe transmission losses between the UMR and LaRC systems.

Measurements of carbon dioxide concentrations were made by using a LI-COR LI-6252 CO_2 Analyzer, which is an NDIR spectrometer. The system used infrared absorption of the 4.26-μm CO_2 absorption band. Because water is an interference in this spectral region, the samples were dried and diluted before introduction into the LI-COR.

4. Results and Discussion

In figure 1(a), the results from the 4, 5, 7, and 8 series of runs, at 80, 100, 80, and 100 percent engine power (EP), respectively, of exhaust samplings on August 10 and 11 are shown. The UMR and LaRC probes were positioned 1 m behind the engine for all these runs. These results reflect only the UMN-determined particle concentrations made by switching back and forth from the UMR and LaRC probes during specific 5-min EP constant runs. Based on these tests, the LaRC sampling probe can be seen to have demonstrated better particle transmission characteristics than the UMR probe. The very notable difference in particle number concentrations (PNCs, in particles/cm^3) between the LaRC and UMR probes for test 2, shown in figure 1(a), is probably misleading, if not spurious. The average UMN PNC determined for 8 independent samplings at 1 m and at 100 percent engine power was $10.2 \pm 5.5 \times 10^7$ particles/cm^3. As can be seen, the PNC determined for the LaRC probe by UMN in test 2 is more than twice that number. Nevertheless, in all cases observed, the LaRC probe had better
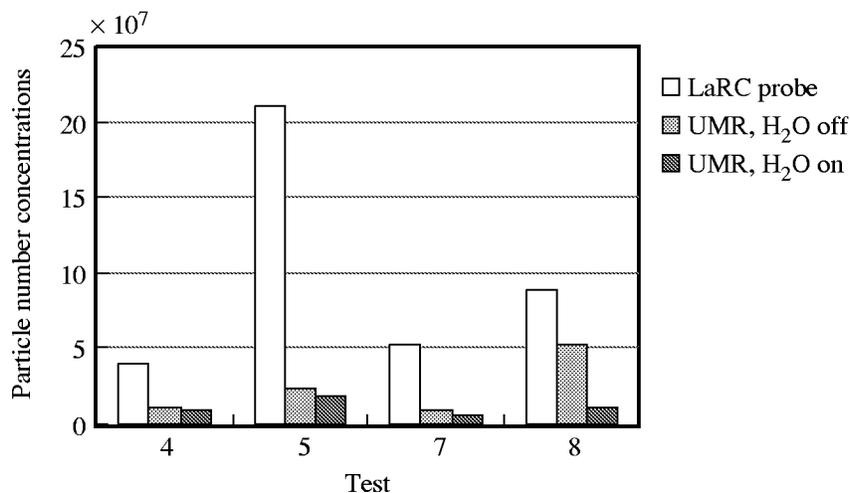
(a) Particle number concentrations.
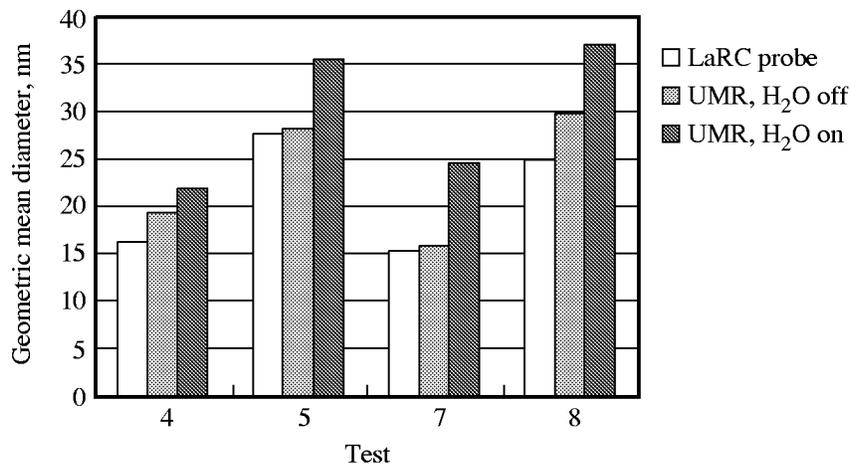
(b) Geometric mean diameter.

Figure 1. Sampling probe evaluations.

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transmission characteristics. These tests also strongly indicated that water cooling diminished particle transmission for the UMR probe.

In figure 1(b), results from the same runs are presented in terms of geometric mean diameters (GMD). The LaRC probe also consistently produced results showing smaller GMDs than the UMR probe; this suggests that fewer small particle losses occurred with this probe. When the UMR probe was water cooled, the GMDs determined were even larger. The UMR probe suffered some damage during the last 100 percent EP run made on August 11, and further tests only involved exhaust samplings by each group utilizing the LaRC probe.

Figure 2 presents the results of a series of runs conducted on August 12, spanning several EPs, ranging from idle (48 percent) to full military power (100 percent). The LaRC probe was located 1 m behind the engine. In figure 2(a), the total particle concentrations were derived by summing the particle counts determined for each size bin. Inversion software resulted in the generation of 30 size bins for the UMN system, 25 size bins for the LaRC system, and an unreported number of size bins for the UMR system. Since the LaRC 3022 counts all submicron particles >5–6 nm in diameter, and requires no inversion technique, PNCs obtained from the LaRC 3022 CPC are also plotted in this figure for comparison. For the data reported by the different groups, about a 50-percent difference typically existed between the highest and lowest PNCs. The LaRC system consistently produced higher PNCs than the UMN system. Likewise, the UMR system consistently produced lower PNCs. When the UMN measurement is used as the standard, then the LaRC/DMA PNCs typically ran about +20 percent above the UMN-determined concentrations, and the UMR PNCs ran about −30 percent below the UMN-determined PNCs.

In figure 2(b), GMDs are shown for the same data. The error bars represent the geometric standard deviation and are only presented for the UMN-determined GMDs. The precision, as would be expected, is less for the smaller GMDs, ranging from about ±20 percent for 10-nm means to about ±7 percent for 30-nm means. GMDs can be seen to noticeably increase at EP greater than 80 percent. In general, reasonably good agreement existed below 85 percent EP. Both the LaRC and UMN measurements indicated a shift to larger particle sizes at >80% percent power.

A similar test series of exhaust sampling runs was conducted at 9 m behind the engine, the results of which are shown in figure 3. These tests were conducted on August 12 and spanned the same engine power range except no run was made at 100 percent power. In figure 3(a), particle concentrations are shown. There appears to be considerably less agreement among the PNCs determined by the participating groups at 9 m than was observed at 1 m. Frequently these differences were as much as a factor of 2 in the determined PNCs. In figure 3(a), the highest particle concentrations are seen to range between 50 and 70 percent power settings. This result was certainly not in accord with our expectations or with the results observed with the earlier series run at 1 m. The UMN PNCs determined at 9 m were consistently higher than determinations made by the other groups. This is also counter to the results during the 1 m series, where the LaRC PNCs were consistently higher than determinations by the other groups. There are many possible explanations for the seemingly contradictory observations between the 1- and 9-m runs. We will speculate on how and why some of these contradictory observations might have occurred at the end of this section.

In figure 3(b), GMDs are shown for the 9-m data. Error bars represent the geometric standard deviation and are presented only with the UMN-determined GMDs. Note, that outside of a few of the UMR determinations at the lower power levels, these data seem to project smaller GMDs for particles collected at 9 m behind the aircraft than for those determined 1 m behind at equivalent engine powers. Further explanations and implications of this will be addressed after presentation of emission indices determined for the 1- and 9-m series.

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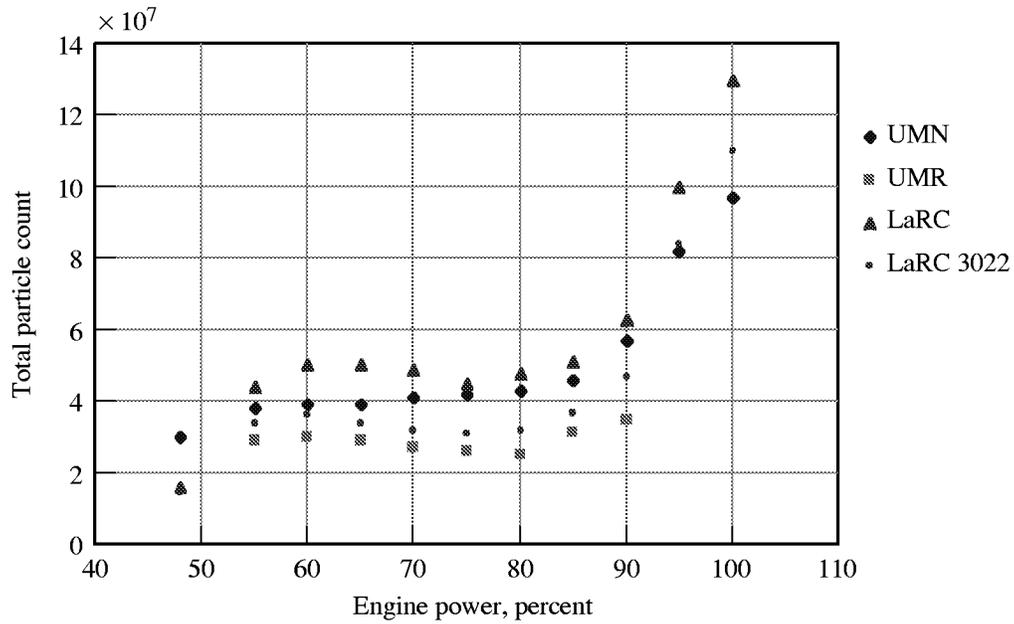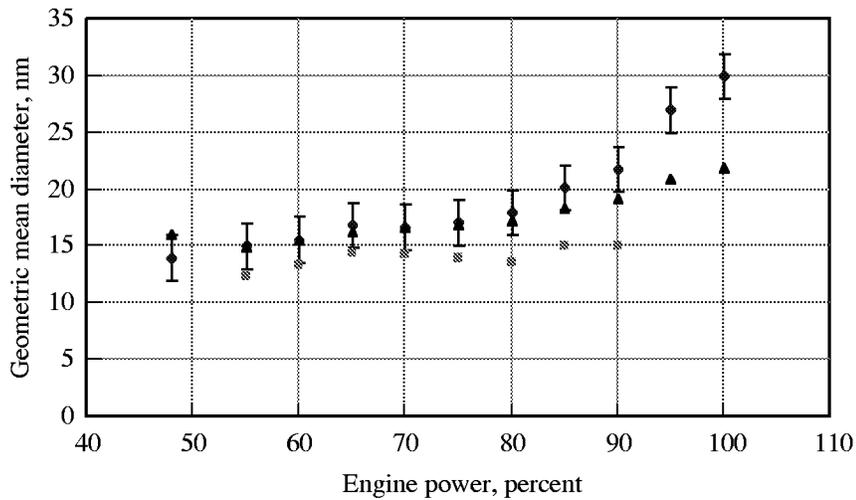
(a) Particle count.

(b) Geometric mean diameter.

Figure 2. Particle concentrations for T-38 at 1 m behind engine.

Figures 4(a) and (b) show the EIs based on measured CO_2 concentrations determined for the 1- and 9-m data, respectively. The overriding assumption here is that essentially all the carbon emissions from the burned fuel end up as CO_2. Thus, if a large difference between levels of background CO_2 and in-plume CO_2 concentrations exist, the difference is attributed to production by fuel combustion. Some rather substantial differences materialize when these data are compared. First, EIs are higher overall (by a factor of about 3 to 5) in the 9-m data; this strongly suggests that new particle formation may have occurred over the 1- to 9-m distance/time interval.

In figure 5, mean CO_2 concentrations are shown in parts per million by volume (ppmv) for both the 1- and 9-m series at the appropriate engine powers. It is notable that the CO_2 concentrations measured

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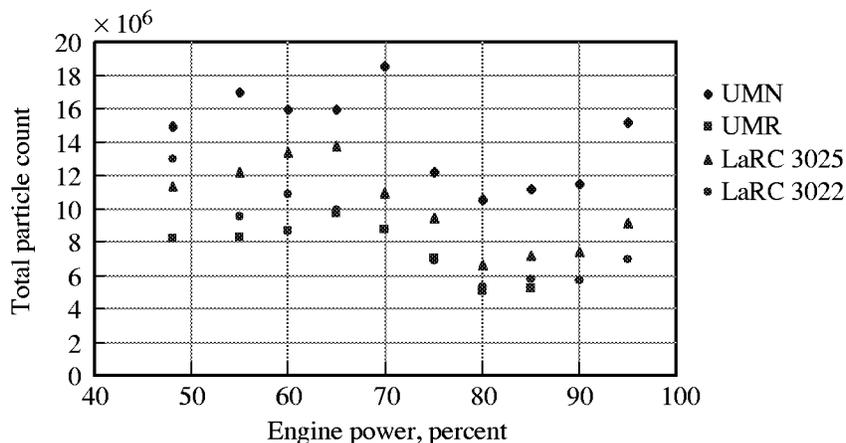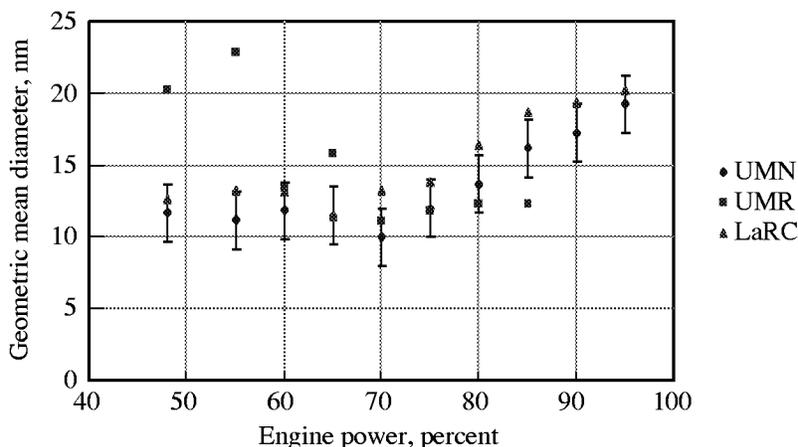
(a) Particle count.

(b) Geometric mean diameter.

Figure 3. Particle concentrations for T-38 at 9 m behind engine.

and shown in figure 5 are about a factor of 10 lower for the 9-m series; this suggests that the mixing of the exhaust with the atmosphere had increased by about a factor of 10 over the 1- to 9-m sampling interval.

Before any speculations, explanations, or conclusions are formed from these results, some important differences in the particle measuring systems deployed by the different groups must be carefully considered. The sampling times required to perform a size distribution analysis were significantly different. The UMN nASA swept the particle size range of 3 to 100 nm in 3 sec. Thus, during a typical 5-min run at a constant aircraft power, UMN was able to perform many analyses. The LaRC system, however, required 1 min to scan particles between 5 and 250 nm. This typically resulted in no more than four analyses being done at each engine power setting. The UMR system scan rate was less important because UMR filled a 40-L tank, and then withdrew a sample from this tank for their DMA analyses. The fill time for the tank determined the sampling time interval. If the engine exhausted constant concentrations and sizes of particles at a given engine power setting, the different sampling time requirements of the systems should present no problem. We believe that the output from the engine was

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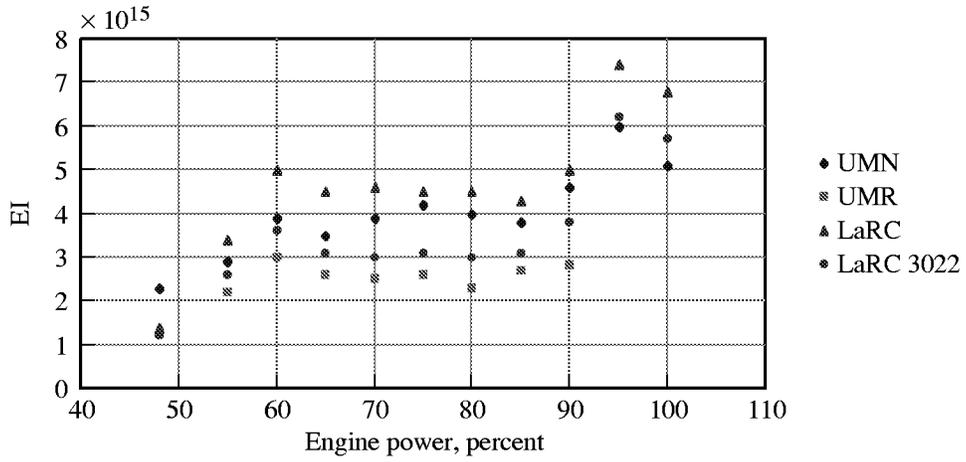
(a) 1 m.
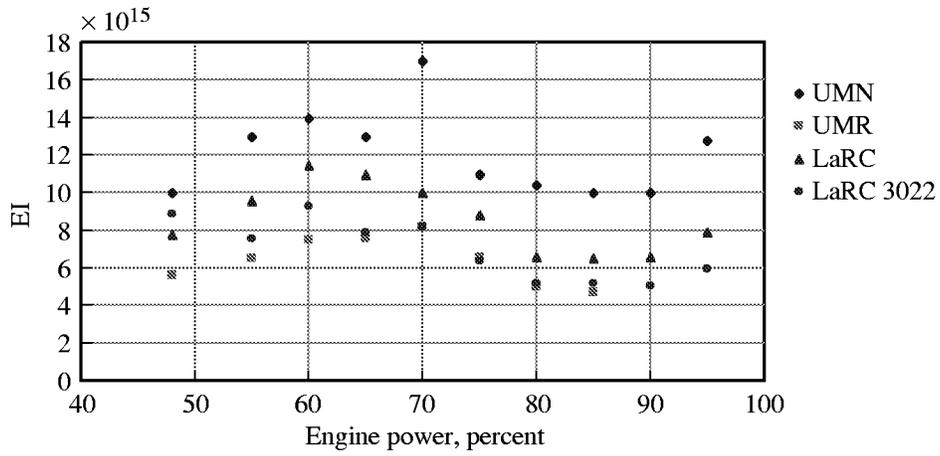
(b) 9 m.

Figure 4. Emission indices determined behind engine.
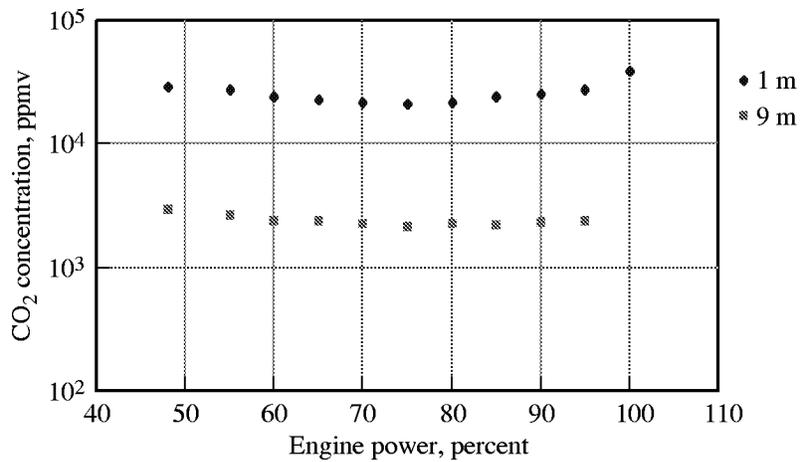
Figure 5. Mean CO$_2$ concentrations at 1 and 9 m behind engine.

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very nearly constant at a given power setting. We observed little change in measured CO_2 concentrations during 5-min constant power runs made 1 m behind the engine, regardless of wind conditions.

However, although the exhaust plume CO_2 was relatively insensitive to crosswinds at 1 m, strong fluctuating crosswinds would move the centerline of the exhaust plume back and forth across the probe at 9 m. The proof of which was the resulting fluctuations of CO_2 concentrations measured during the 5-min runs. Since the exhaust samples analyzed by each group were from the same probe and the same instruments had compared well in the laboratory phase of these intercomparisons (Cofer et al. 2001), a likely contributor to the larger discrepancies observed at 9 m was the combination of centerline plume movement and the different response times of the systems. Behavior such as that just described would impact 1-min measurements much more than 3-sec measurements.

When the 1- and 9-m runs are compared, some rather surprising observations can be made. First, a large increase in PNCs (fig. 2(a)) at EP $\geq$ 90 percent at 1 m occurs. Although there is no 100-percent EP run at 9 m, the suggestion of such a trend at 95-percent EP is much less conclusive. Second, when PNCs of the 9-m runs are multiplied by 10 (the atmospheric dispersion/dilution based on the CO_2 concentrations shown in fig. 5), the 9-m concentrations exceed the 1-m concentrations. Third, when the 1- and 9-m runs at EP < 85 percent are examined, the 9-m runs actually appear to have higher PNCs, totally counter to the 1-m results. Likewise, when the EIs determined for the 1- and 9-m runs are compared (figs. 4(a) and (b)), the same trends are observed.

An attempt is now made to explain how some of the seemingly contradictory PNC determinations made between the runs at 1 and 9 m might have occurred. It is very clear (fig. 2(a)) that at 1 m and at EPs of 55 to 85 percent, PCNs do not change significantly and equally clear that at EP > 85 percent, PCNs increase dramatically. When the corresponding series of EP runs are viewed at 9 m (fig. 3(a)), PNCs appear to be higher at EP $\leq$ 70 percent, systematically decrease at EPs between 70 and 80 percent, and then systematically increase again at EPs between 80 and 95 percent. We now speculate on several factors that could help explain the differences in the observations made at 1 and 9 m. Exhaust velocity and temperature will vary with EP at any distance from the engine. At idle, exhaust gas temperature is about 520°C. It then drops steadily to about 405°C at 80 percent EP. The temperature then progressively increases to about 640°C at 100 percent EP. Exhaust gas velocity, however, continually increases with increasing EP. Dilution resulting from entrainment of ambient air increases substantially as distance from the engine increases as well. In our case, the plume sampled at 9 m had diluted approximately tenfold over that at 1 m. It is our speculation that at 1 m the exhaust plume temperatures were always above some threshold value limiting new particle formation. Thus, essentially all particles were soot carbon. Nine meters, however, may be in a transition region for particle formation. The combination of cooling and the forward velocity of the exhaust plume may have generated some interesting results. Because the rate of exhaust sample arrival time at the probe progressively shortens as EP increases and the temperature increases, particularly above 80 percent EP, nonsoot particle formation may have been diminished relative to new particle formation at EP > 80 percent. The increase in PNC seen in figure 3(a) at EP > 90 percent follows the behavior of the 1-m series of runs.

When the GMDs for the two series of runs are examined, placing particular emphasis on the UMN nASA measurement, the GMDs for each corresponding EP can be seen to be smaller for the 9-m runs; this is also consistent with the new particle formation speculation. Both the higher PNC EIs and the smaller GMD observed at 9 m suggest nonsoot small particle formation at 9 m. We believe this nonsoot fraction of new particles was relatively absent at 1 m.

Finally, when the EIs determined behind the LaRC T-38 in these tarmac experiments are compared with prior (Anderson, Cofer, and Brunke 1998; Anderson, Cofer, and Hudgins 1998) EI determinations

made behind the LaRC T-38 in flight at cruise altitudes, some interesting observations can also be made. First, based on temperature considerations, we assume that the EIs determined 1 m behind the LaRC T-38 essentially include no volatile fraction. The nonvolatile EIs at 1 m range from about 2×10^{15} to 6×10^{15} particles generated per kilogram of fuel burned over the interval from 48 to 100 percent EP. The nonvolatile EIs determined several kilometers behind the LaRC T-38 in flight (Anderson, Cofer, and Brunke 1998) ranged from 0.4×10^{16} to 2×10^{16} particles/kg, over an interval of 65 to 100 percent. However, on the average, the EIs determined in flight were roughly twice as high. It does not seem reasonable that any new soot carbon would form beyond 1 m aft of the turbine exhaust. The heater during the in-flight determinations was operated at 150°C, however, and may not have evaporated the larger volatile sulfate particles that formed in the plume. In addition, other nonvolatiles, such as sulfate salts, might be produced from the exhaust interacting with the atmosphere. The fact that the particle EIs roughly double going from 1 to 9 m behind the turbine exhaust certainly suggests potential new particle formation.

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13. ABSTRACT *(Maximum 200 words)*
During August 1–14, 1999, NASA's Atmospheric Effects of Aviation Project (AEAP) convened a workshop at the NASA Langley Research Center to try to determine why such a wide variation in aerosol emissions indices and chemical and physical properties has been reported by various independent AEAP-supported research teams trying to characterize the exhaust emissions of subsonic commercial aircraft. This workshop was divided into two phases, a laboratory phase and a field phase. The laboratory phase consisted of supplying known particle number densities (concentrations) and particle size distributions to a common manifold for the participating research teams to sample and analyze. The field phase was conducted on an aircraft run-up pad. Participating teams actually sampled aircraft exhaust generated by a Langley T-38 Talon aircraft at 1 and 9 m behind the engine at engine powers ranging from 48 to 100 percent. Results from the laboratory phase of this intercomparison workshop are reported in this paper.

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