22 June 2004

Dear Colleagues,

In response to concerns expressed by users of the LTI starboard samples in ACE-Asia, I have recalculated the enhancement factors, EF, for LTI porous diffuser and the penetration, P, of particles through the bend just aft of the porous diffuser. In my previous memo, file dated 6-18-2004, I provided you with the information needed to recalculate the enhancements. This was not viewed by some as being all that useful. I am now providing you with the correct enhancements and the penetrations in PDF files. The files are named ls_131ff0X_ef_cor.pdf and ls_131rfYY_cor.pdf. Files being distributed at this time have values of X =1,2,3, 5,6,7 and values of YY from 01 through 18 except for 03 which is unavailable. This memo describes these files and their content. These files contain the corrections to the initial calculations that I described in my memo of 6-18-2004. **Do not apply the corrections in the memo of 6-18-2004 to the data provided in the files ls_131rfYY_cor.pdf or ls_131ff0X_cor.pdf. These files contain the corrected data.**

You will certainly need to manipulate the data in these files. To do that, you can open them in Acrobat 5.0, select all, copy and paste them into Excel. In Excel, you Tools-> Text to Columns-> delimited->space etc etc.

I choose pdf s to save space in your inbox. If you want the excel version of these files, let me know. They sum to 35 Mb and I can either send them via email or burn a CD for you and mail it if you give me a current postal address.

Quantitative Description of the Error and the Correction Factors:

The Enhancement Factor was systematically overstated in the files that I provided you in April 2002. The overstatement resulted from a clerical error. We calculated the EF using particles having a density of 1550 kg/m^3 and we reported the results as if they had a density of 1000 kg/m^3. Therefore, we have reported the enhancements for particles having an aerodynamic diameter, D_a, of 12.4 µm as if they had an aerodynamic diameter of 10 µm and so on. The reference to aerodynamic diameter follows from the fact that the Stokes Number captures most of the variability of the Enhancement Factors for a given ratio of sample flow to total flow. Tables 1 and 2 describe the magnitude of the errors in the EF's I provided in April 2002.

Table 1. Errors in files circulated in April 2002 describing the starboard EF prior to 20010416 (diffuser f1). The median is calculated from a population of 5648 30s intervals having a ratio of sample flow to total flow less than 0.5.

Physical Diameter, Dp, µm	Density, kg/m^3	Aerodynamic Diameter, Da, µm	Median of Ratios of Incorrect EF to the Correct EF	Standard Deviation of the Ratio
10	1550	12.45	1.27	0.024
7	1550	8.71	1.181	0.020

5	1550	6.23	1.123	0.017
3	1550	3.73	1.055	0.010
1	1550	1.25	1.008	0.001

Equation for the ratio of incorrect EF to correct EF for this time period on Starboard side:

$$\frac{\mathit{Wrong}\ \text{EF}}{\text{Right EF}} = 0.023859 * D_a + 0.9736 \qquad (1)$$

Table 2. Errors in files circulated in April 2002 describing the starboard EF after 20010412 (diffuser f2). The median is calculated from a population of 12,522 30s intervals having a ratio of sample flow to total flow less than 0.5.

Physical Diameter, Dp, μm	Density, kg/m^3	Aerodynamic Diameter, Da, μm	Median of Ratios of Incorrect EF to the Correct EF	Standard Deviation of the Ratio
10	1550	12.45	1.33	0.033
7	1550	8.71	1.23	0.040
5	1550	6.23	1.149	0.033
3	1550	3.73	1.066	0.018
1	1550	1.25	1.009	0.00346

Equation for the ratio of wrong EF to the right EF for this time period on the starboard side:

$$\frac{\mathit{Wrong}\ \text{EF}}{\text{Right EF}} = 0.029386 * D_a + 0.966499 \qquad (2)$$

Definition of the Enhancement Factor and Penetration to the LTI exit.

The Enhancement Factor (EF) equals the ratio of the mixing ratio at the exit of the diffuser to the ambient mixing ratio. Mixing ratios are aerosol properties expressed as quantity of aerosol property per unit mass of air.

$$EF = \frac{\text{Aerosol Property Mixing Ratio at Exit of LTI Diffuser}}{\text{Ambient Aerosol Property Mixing Ratio}} \qquad (3)$$

To include losses in transport from the diffuser to the first splitter in the aircraft, the penetration, P, is defined as:

$$P = \frac{\text{Aerosol Property Mixing Ratio at Entrance to First Splitter}}{\text{Aerosol Property Mixing Ratio at the Exit of the Diffuser}} \qquad (4)$$

EF accounts for the inertial effects in the porous diffuser where much the flow is removed and the mixing ratios of particles are increased due to inertial effects. EF is calculated in FLUENT where the flow in the inlet and particle trajectories are calculated.

Determination of EF and P.

We calculated the values of EF using Fluent for a number pressures and flows that covered the range of conditions experienced on the aircraft. For ACE-Asia, we have calculated the internal flow in the diffuser for something like 60 flows and have calculated 10 sets of particle trajectories for each flow. Each set of particle trajectories tracked 999 particles. We then examined the variation to find a scheme that would permit interpolation of the results to all the conditions experienced in research flight. This examination showed that for a given ratio of sample flow (that is the flow exiting the rear of porous diffuser) to total flow, the enhancement is primarily a function of the Stokes number of the particle in the throat of the inlet. That Stokes number depends primarily on the velocity of the air in the inlet throat, the particle diameter and particle density. The slip correction is not very significant because the smallest particles of interest (1 um) have the smallest corrections anyway. So the Stokes number, and EF, varies with true air speed of the aircraft since the inlets were very nearly isokinetic on ACE-Asia. The true air speed varied with the aircraft altitude and the flight objectives. Therefore, there is not a single curve fit that gives the correction as a function of the particle size. We have published papers from TEXAQS2000 and PELTI and ITCT where the enhancements are calculated for each time interval and applied to the size distribution measurements made during that time interval. This is very similar to our standard procedure on high altitude aircraft where we apply a non-isokinetic correction for each time interval. The present calculation proceeds as follows:

$$\mathrm{St} = \frac{\rho_{\mathrm{p}} Dp^2 C(Dp) V}{9 \mu d} \qquad (5)$$

St is the Stokes number. V is the velocity of the gas in the throat of the inlet. In the case of ACE-Asia, that velocity is usually nearly equal to the true airspeed of the aircraft. ρ_p is the particle density, Dp is the particle diameter. μ is the viscosity which depends on the air temperature. C(Dp) is the slip correction. Values of viscosity and velocity are determined from the data acquired during flight by the LTI,.

Our investigations showed that we could accurately (maximum scatter less than 12%, average deviation a few percent) calculate the Enhancement Factors, EF, using the following linear approximation:

$$\mathrm{EF} = 1.01 + m^* \,\mathrm{St} \qquad (6)$$

where m depends upon the ratio of sample flow to total flow in the inlet at the time of interest. The mass flows are also determined from the LTI data.

$$m = 1.3435*R^2 - 0.9441*R + 0.2825 \quad (7)$$

$$m = -1.171*R^3 + 1.5103*R^2 - 0.7709*R + 0.2426 \quad (8)$$

Equation 7 applies to the Starboard side in ACE-Asia prior to 20010416 (porous diffuser f1) and equation 8 applies to the starboard side in ACE-Asia after 20010412 (porous diffuser f2).

Losses in the bend behind the porous diffuser and upstream of the exit of the LTI are accounted for in the calculation of P, the penetration. These losses result from gravitational settling and inertial deposition on the walls of the tube that carries the sample flow from the LTI diffuser into the aircraft. These losses were evaluated in a FLUENT calculation of the flow and particle trajectories in the tube for one case in which the velocity in the tube was 4 m/s. The results of these FLUENT calculations were compared with the calculation of losses using Baron and Willeke (2002) 8-51 to 8-53 (Aerosol Calculator, aerocalc.xl, version 01 October 01, line 754, "Penetration efficiency of an inclined tube under laminar and turbulent flow conditions, gravitational settling (B&W 8-51 to 8-53; W&B 6-37, 6-40)" , where the result was taken from cell B773 for laminar flow.) and Baron and Willeke (2002) 8-66 (Aerosol Calculator, aerocalc.xl, version 01 October 01, line 858, "Loss in a bent section of circular tubing (B&W 8-66 to 8-68; W&B 6-52, 6-53)," where the result was taken from cell B872 for laminar flow). The losses in transport depend on the particle Stokes number and the flow in the tube. The Fluent calculation was made for a particular set of conditions and was not applicable to the entire range of flows seen in ACE-Asia. Therefore, the comparison was made with the formulations in the literature that would permit estimation of losses over the range of conditions seen in ACE-Asia. The FLUENT calculations and the product of the penetrations from formulations in Barron and Willeke agreed to a within several percent. This agreement justifies the use the referenced equations.

<u>Contents of the Provided Files</u> (ls_131ff0X_cor.xls and ls_131rfYY_cor.xls)

The product of EF and P provides the ratio of aerosol property mixing ratio at the exit of the LTI, just upstream of the first splitter in the aircraft to the aerosol property mixing ratio in the ambient. The product EF*P depends upon the flow conditions in the inlet which in turn depends on the flight conditions of the aircraft. There is no single curve fit which will permit us to express EF or EF*P as a function of particle size. Rather, EF and EF*P depend on particle Stokes number and flow conditions. Thus, I have provided values of EF and EF*P for 30 second intervals in the flights listed above. Data are provided for intervals in which LTI performance met the requirements for laminar, well-understood performance. The values of EF and EF*P are provided for particles of diameter 10, 7, 5, 3 and 1 μm and having a density of 1550 kg/m^3. Since the principal variable is the Stokes number and slip correction is not very important, the calculations can be applied to particles having aerodynamic diameters up to 12.45 μm.

Table 3. Location of the values of EF and EF*P in the provided excel files. Note that the values of EF and EF*P that correspond to these aerodynamic diameters change with time and are listed for each 30 second interval in the files. Each row of the file corresponds to a specific time during the flight specified in column A in UTS.

Column->	K	L	M	N	O	P	Q	R	S	T
D, aerodynamic (microns)	12.45	8.71	6.22	3.73	1.24	12.45	8.71	6.22	3.73	1.24
Diameter (microns)	10	7	5	3	1	10	7	5	3	1
Density (kg/m^3)	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550
Variable	EF	EF	EF	EF	EF	EF*P	EF*P	EF*P	EF*P	EF*P

As a result of Equation 6, the values of EF, columns K through O, are linear with the square of aerodynamic diameter. Values of EF*P, columns P through T, are nearly linear with the square of aerodynamic diameter. Interpolations will have to be done to determine EF or EF*P for aerodynamic diameters between the listed values.
The definition of aerodynamic diameter useful for these calculations is given in equation 9:

$$(Da)^2 = sg*(Dp)^2 \tag{9}$$

where sg is the ratio of the density of the particle to the density of the unit density sphere. In SI units, sg=particle density/1000. Calculations have shown that the neglect of the slip correction is not significant in this case because the variation in EF and EF*P is unimportant where slip is important.

The EF depends upon Stoke and particle density because of the motion that occurs outside of Stokes regime in the inlet. However, calculations in Fluent have demonstrated that the variation due to density is small. Therefore, the experimenter who is interested in particles having density different that 1550 kg/m^3 can still accurately determine EF or EF*P by determining the aerodynamic diameter of the particle of interest with equation 9 and interpolating among the aerodynamic diameters in Table 3 .

<u>Acknowledgement of the LTI in your publications.</u>

If the LTI has contributed to your science, please acknowledge that in you publications. I will be submitting a manuscript describing the performance of the LTI in ACE-Asia before the end of the summer. Currently the following manuscripts are in press:

Function and Performance of a Low Turbulence Inlet for Sampling Super-micron Particles from Aircraft Platforms, Wilson, J.C., Lafleur, B. G., Hilbert, H., Seebaugh, W. R., Fox, J.,Gesler, D. W., Brock, C. A., Huebert, B. J., Mullen, J., in press: Aerosol Science and Technology, 2004.

PELTI: Measuring the Passing Efficiency of an Airborne Low Turbulence Aerosol Inlet, Barry J. Huebert, Steven G. Howell, David Covert , Timothy Bertram1, Anthony Clarke1, James R. Anderson, Bernard G. Lafleur, W. R. Seebaugh, James Charles Wilson, Dave Gesler, Byron Blomquist, Jack Fox, in press: Aerosol Science and Technology, 2004.