Size Classification Without Charging – Characterization Of The New Aerodynamic Aerosol Classifier

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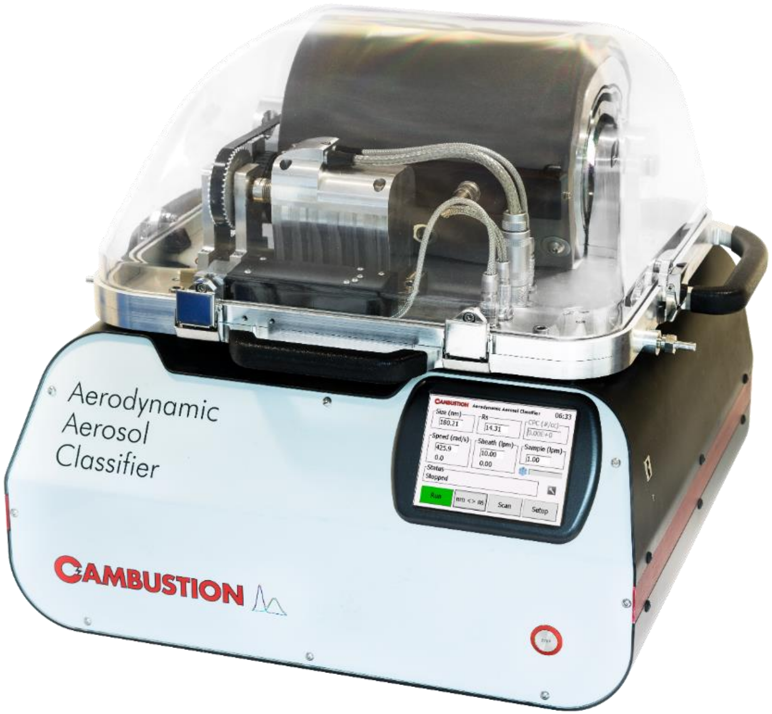
An introduction to the AAC (at AAC!)

The Aerodynamic Aerosol Classifier solves **two** problems in Aerosol Science:

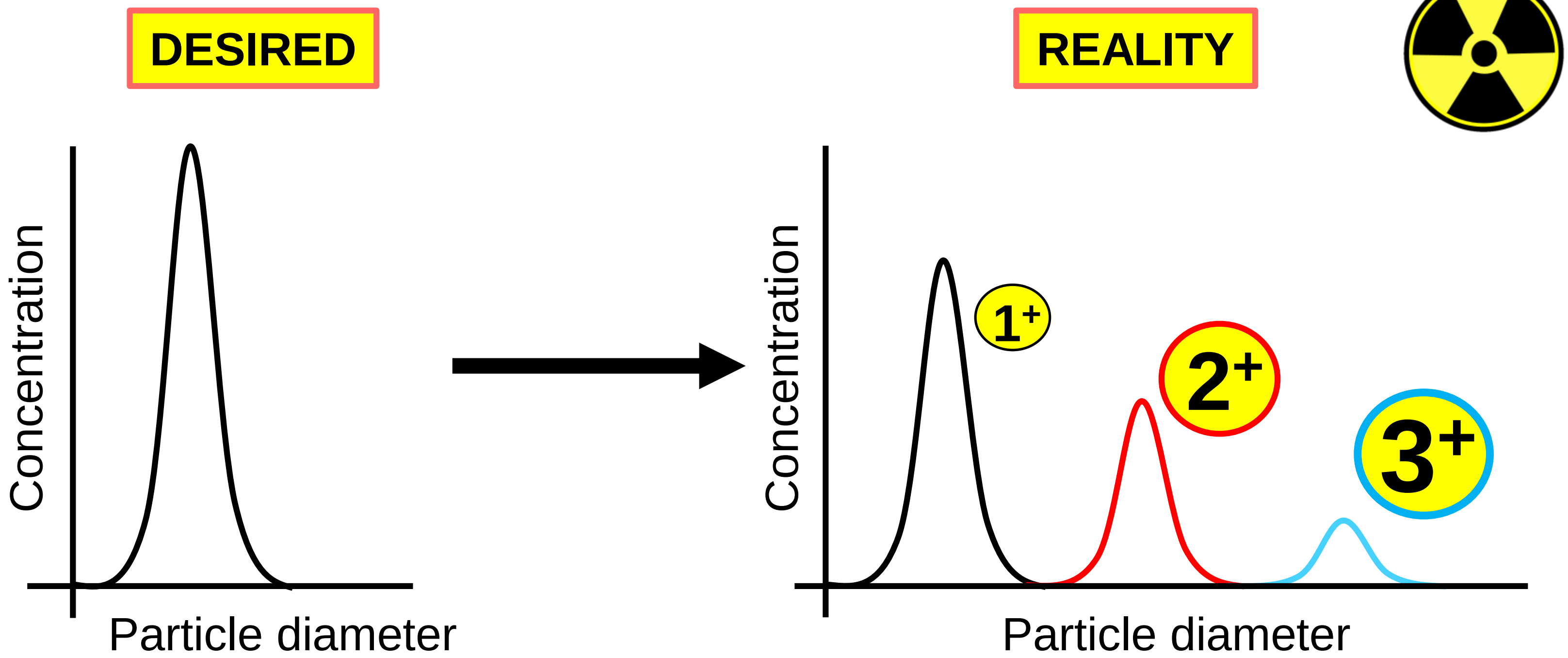
1. How do I select a monodisperse size classified aerosol without multiple / zero charging artefacts?

2. How do I select a monodisperse aerosol based upon Aerodynamic Diameter?

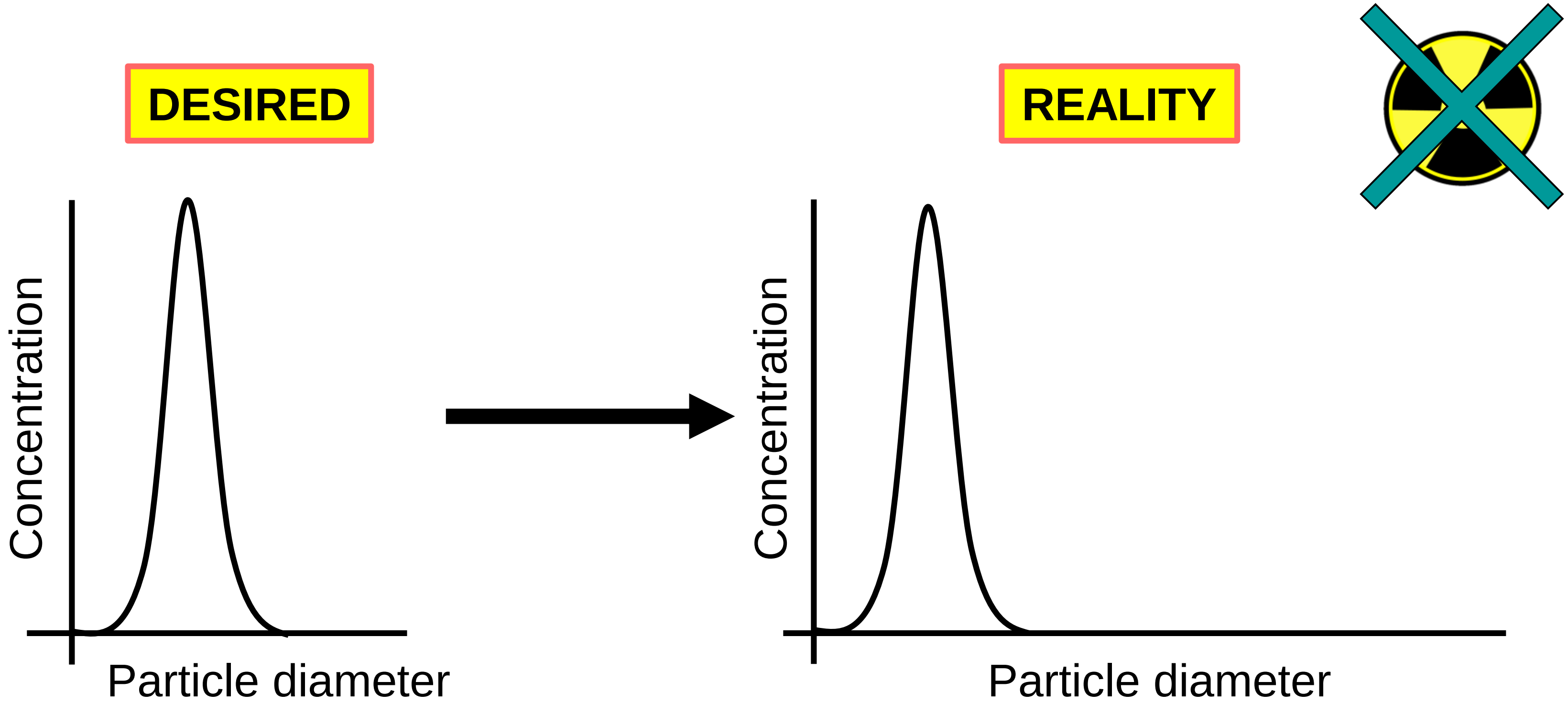


True monodisperse aerosol using AAC

DMA produces ***multiple peaks***



True monodisperse aerosol using AAC

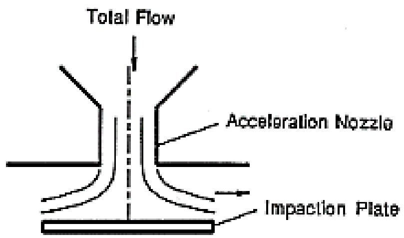


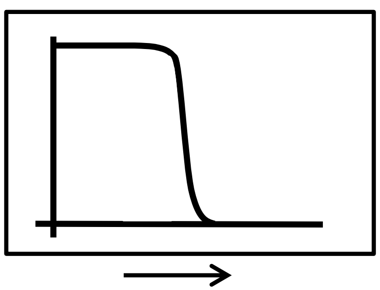
The AAC produces a ***truly*** ***monodisperse*** *aerosol*

Classification by Aerodynamic Diameter

Rather than just determining the sizes of particles in an aerosol stream, it is often desirable to be able to classify them for further online analysis.

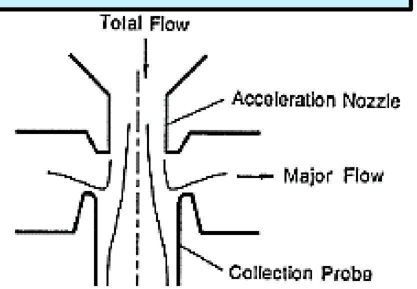
Impactor – "low pass"

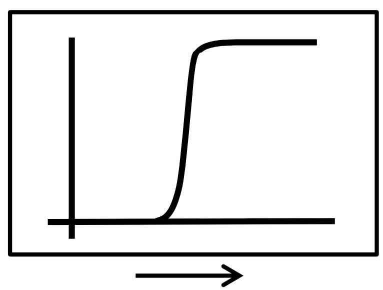




Aerodynamic Diameter

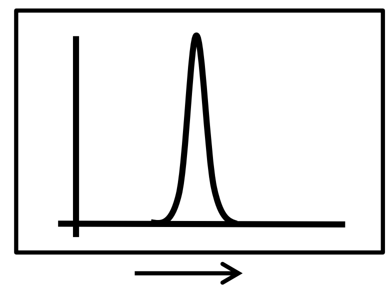
Virtual Impactor – "high pass"





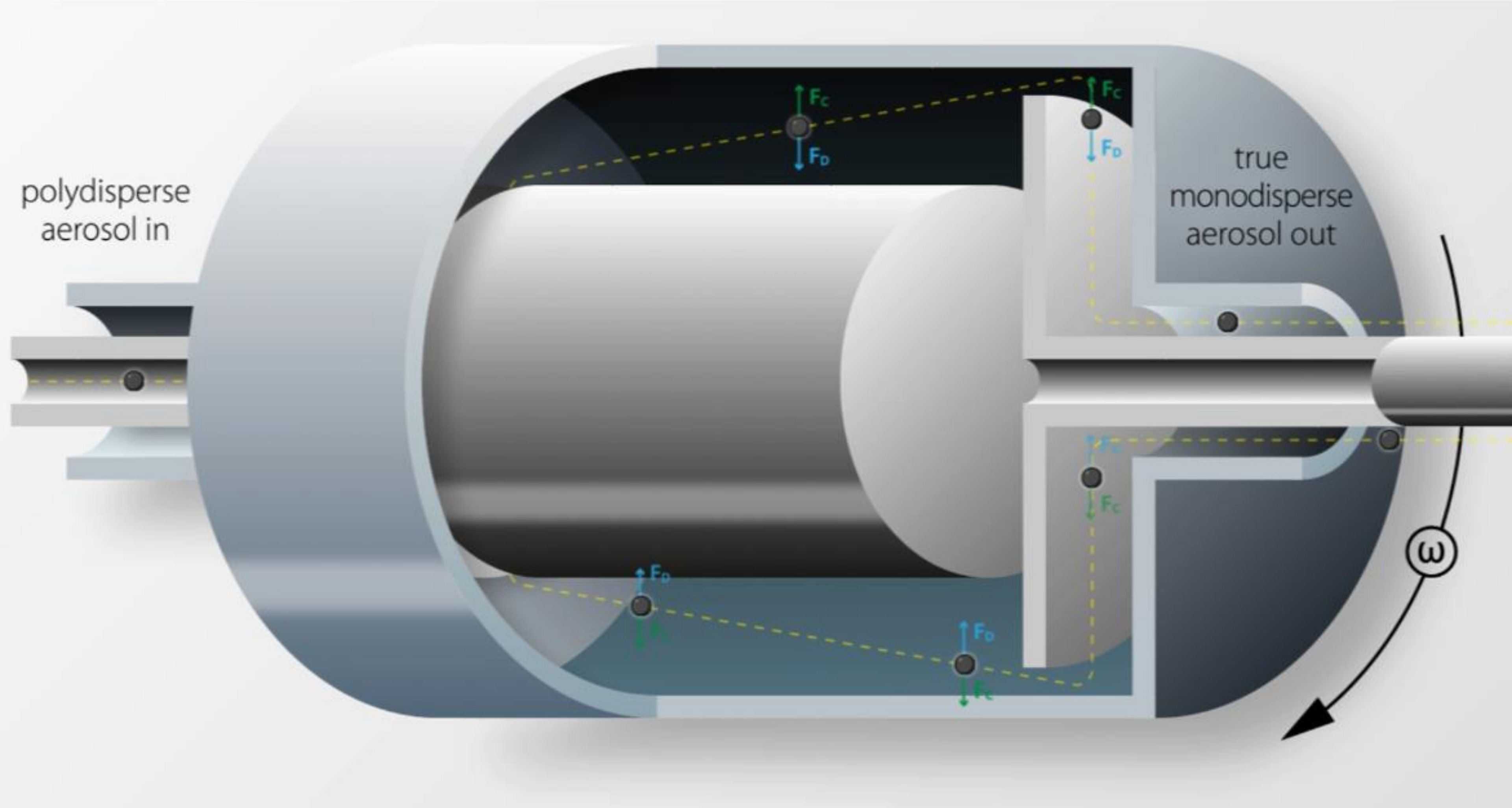
Aerodynamic Diameter

"Band pass"



Aerodynamic Diameter

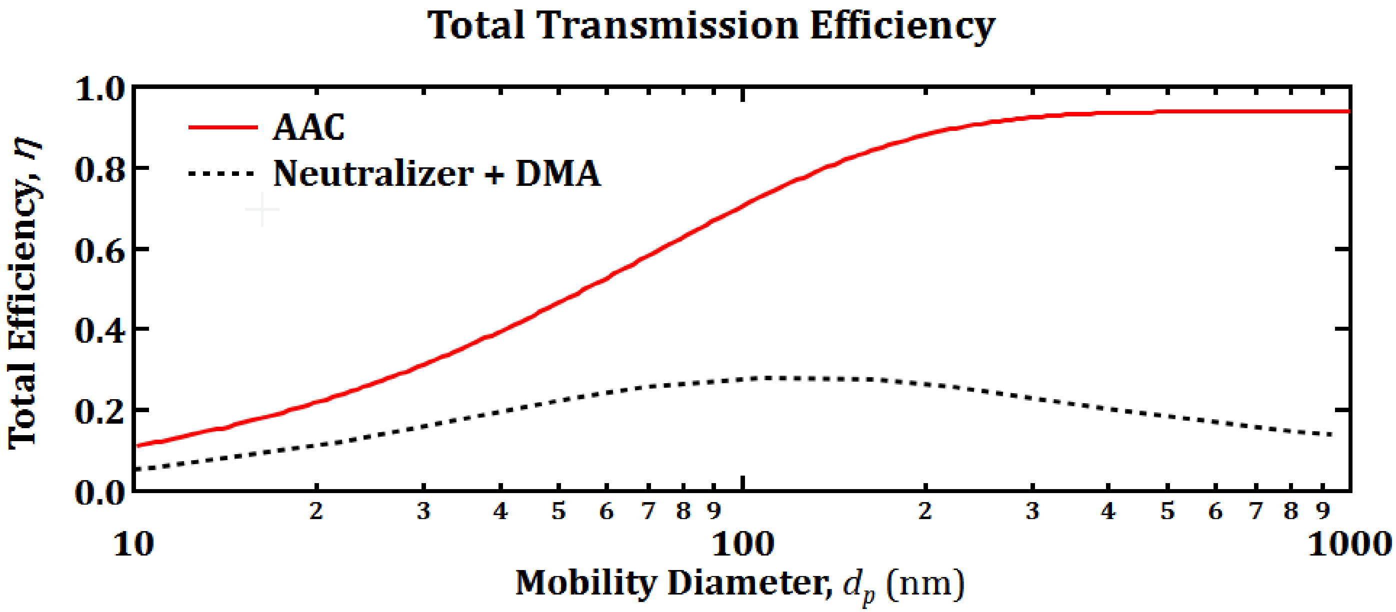
AAC Principle



Go to https://www.cambustion.com/products/aac/animation to see animation

Efficiency compared to Neutraliser + DMA

dp [nm]	Number of charges										
	q=-5	q=-4	q=-3	q=-2	q=-1	q=0	q=1	q=2	q=3	q=4	q=5
2	0	0	0	0	0.0083	0.9742	0.0075	0	0	0	0
5	0	0	0	0	0.0225	0.9693	0.0189	0	0	0	0
10	0	0	0	0	0.0514	0.9124	0.0411	0	0	0	0
20	0	0	0	0	0.1096	0.7931	0.0846	0	0	0	0
50	0	0	0	0.0114	0.2229	0.5814	0.1696	0.0066	0	0	0
100	0	0.0001	0.0037	0.0561	0.2793	0.4259	0.2138	0.0317	0.0017	0	0
200	0.0005	0.0053	0.0340	0.1211	0.2641	0.2991	0.2043	0.0719	0.0153	0.0018	0.0001
500	0.0207	0.0504	0.0980	0.1490	0.1816	0.1818	0.1403	0.0891	0.0440	0.0173	0.0054
1000	0.0584	0.0854	0.1113	0.1261	0.1385	0.1235	0.1039	0.0754	0.0500	0.0293	0.0154



Selection of Sheath Flow and Speed

Relaxation time, τ, of an aerosol particle is analogous to a characteristic acceleration time for a car, e.g. its "0-60" mph time (*Hinds, 1999; pp 111-116*)

- i.e. the time taken to adjust to a new condition of forces

Cunningham slip

$$\tau \equiv mB = \frac{C_c(d_{ae})\rho_0 d_{ae}^2}{18\mu} = \frac{2Q_{sh}}{\pi\omega^2(r_i+r_o)^2 L}$$

mass   mobility

F. Tavakoli & J. S. Olfert (2013).

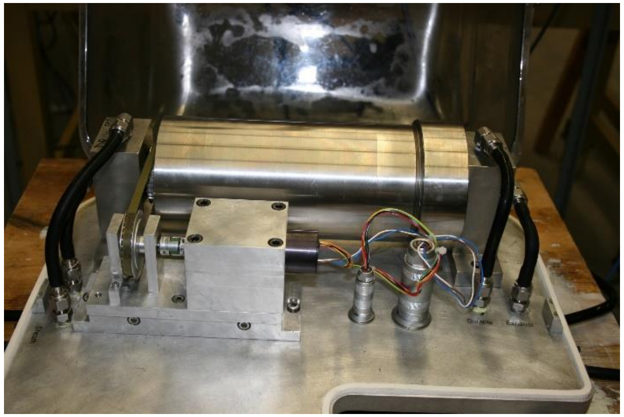
for (balanced) AAC sheath flow Q_{sh}, rotational speed ω, classifier inner and outer radii r_i and r_o and length L, gas viscosity μ and unit density ρ_0

Resolution parameter (*R*), as for a DMA, is $Q_{sh}/Q_{aerosol}$

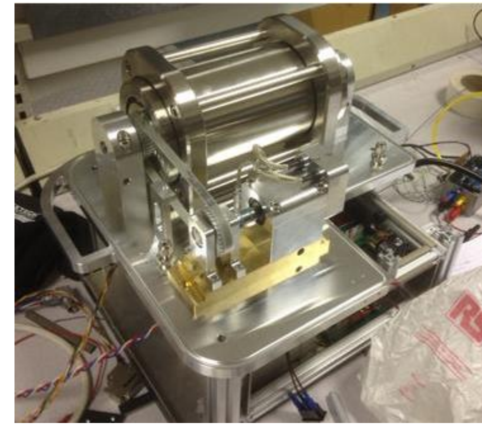
Required resolution sets Q_{sh}, then solve for ω for a given d_{ae}

AAC "History"

- First prototype, Alberta / Cambustion (2010–14)

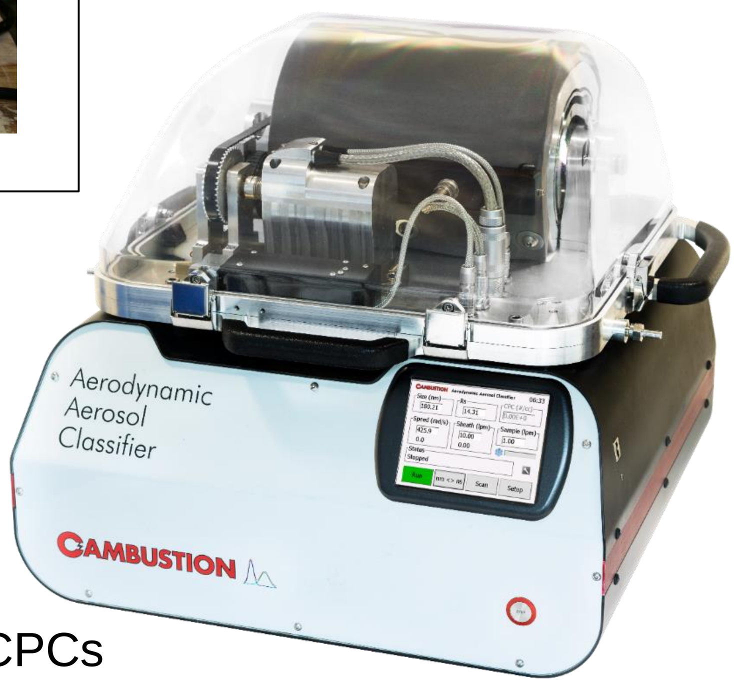


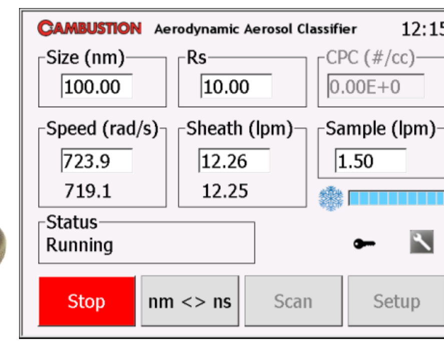
- Second prototypes, Cambustion / Alberta (2015–16)

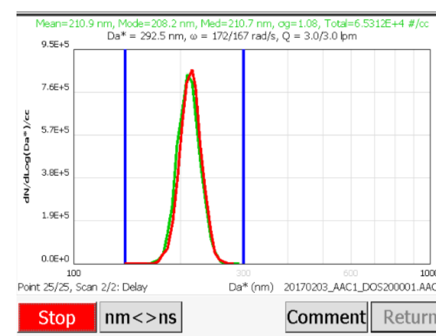


- Production instruments, Cambustion (2017–)

25 nm – 5 μm+ size range
→7000 rpm, 15 lpm sheath
Step scanning function
Connects to a wide range of CPCs



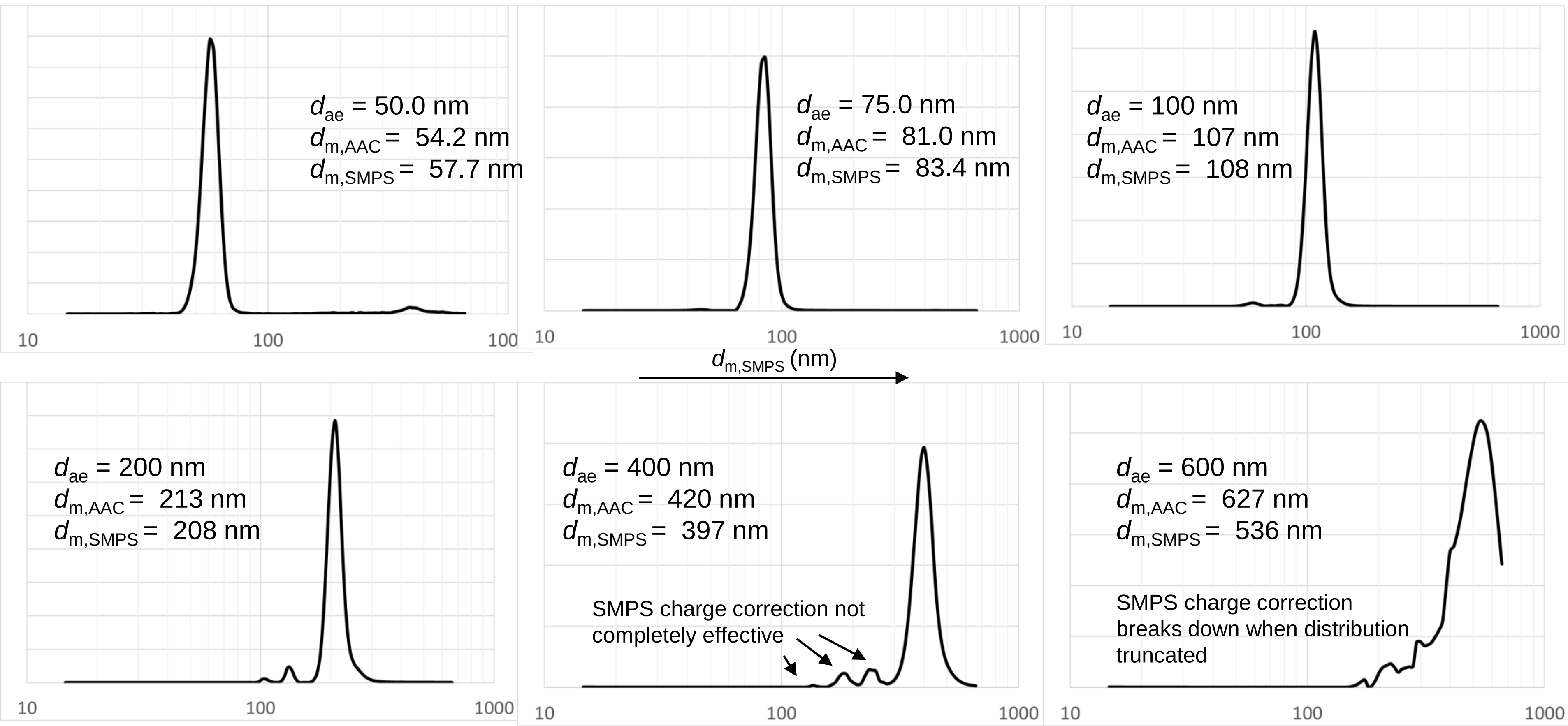




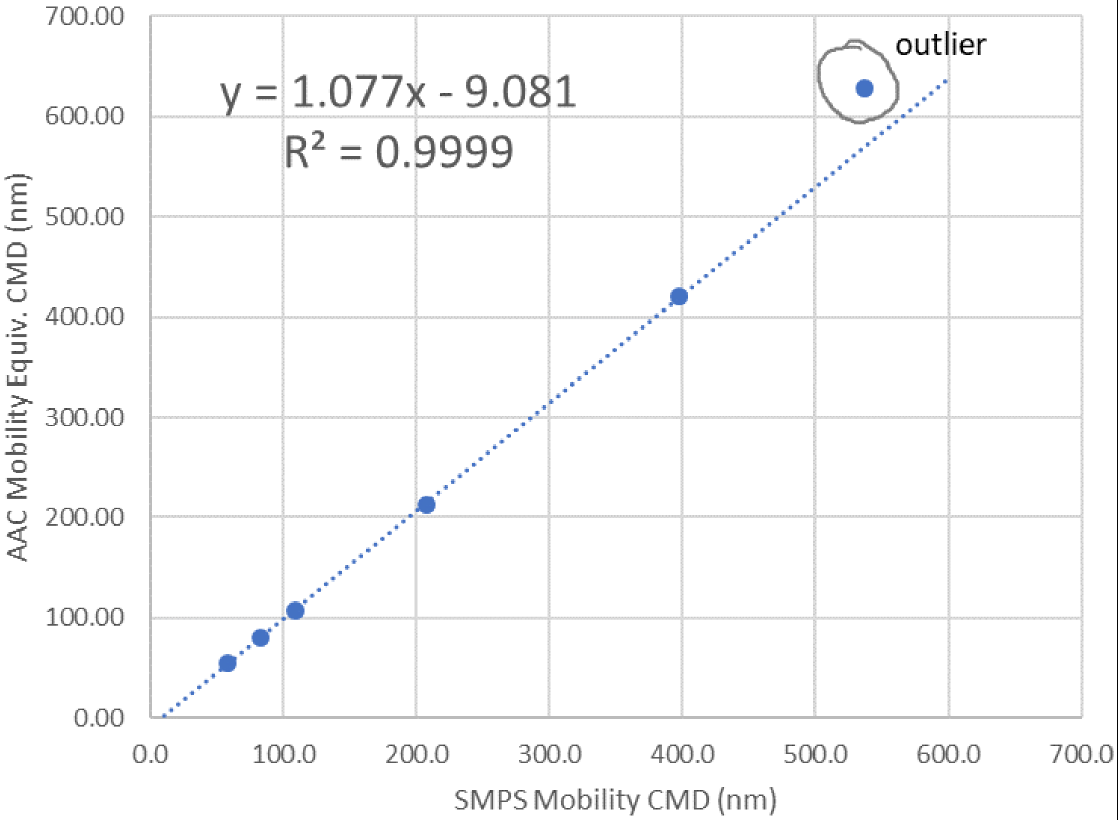
Monodisperse output

DOS → AAC → TSI SMPS

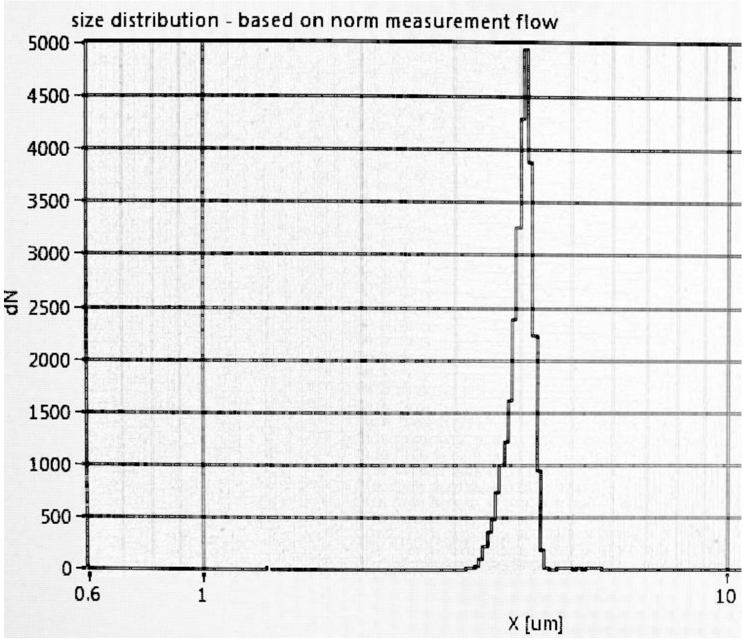
AAC d_{ae} setpoint converted to mobility diameter d_m, SMPS charge correction **on** (AIM)



Monodisperse output summary



4 µm DOS particles, PALAS Welas spectrum of AAC output



Step Scanning Inversion

By applying methods used by Stolzenburg and McMurry (2008) on the DMA, it can be shown* that

Size spectral density at point *i* →

$$\left.\frac{\mathrm{d}N}{\mathrm{dlog}d_{ae}}\right|_i \approx \frac{\ln(10)\cdot N_i}{\eta_i \cdot \left.\frac{\mathrm{dlog}d_{ae}}{\mathrm{dlog}\tau}\right|_i \cdot \beta_i^*}$$

← CPC concentration at point *i*

Penetration efficiency ↗

where $\beta^* = \left(1+\frac{1}{\beta}\right)\cdot\ln(1+\beta) - \left(1-\frac{1}{\beta}\right)\cdot\ln(1-\beta)$ & $\beta = \frac{1}{R_\tau} = \frac{Q_{\text{aerosol}}}{Q_{\text{sheath}}}$

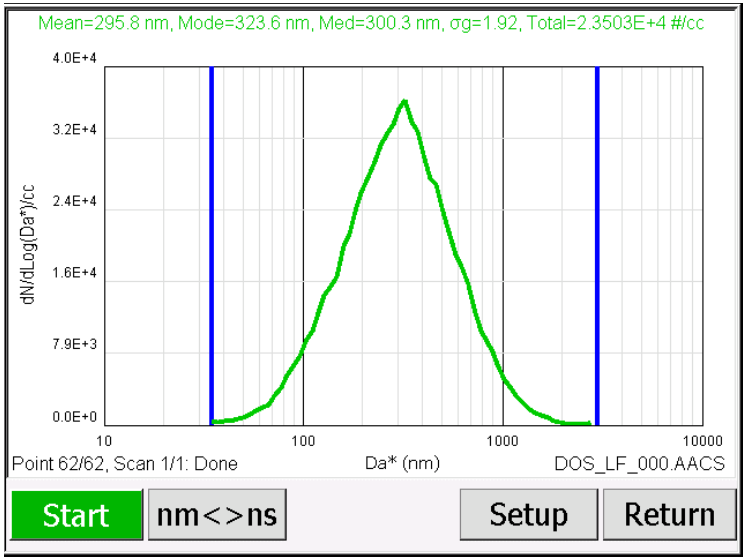
And by differentiating $\tau \equiv \frac{C_c(d_{ae})\rho_0 d_{ae}^2}{18\mu}$

$$\frac{\mathrm{dlog}(d_{ae})}{\mathrm{dlog}(\tau)} =$$

$$C_c(d_{ae})\cdot d_{ae}\cdot\left[2\cdot d_{ae} + 2.34\cdot\lambda + 1.05\cdot\lambda\cdot\exp\left(-0.39\cdot\frac{d_{ae}}{\lambda}\right)\cdot\left(1-\frac{0.39\cdot d_{ae}}{\lambda}\right)\right]^{-1}$$

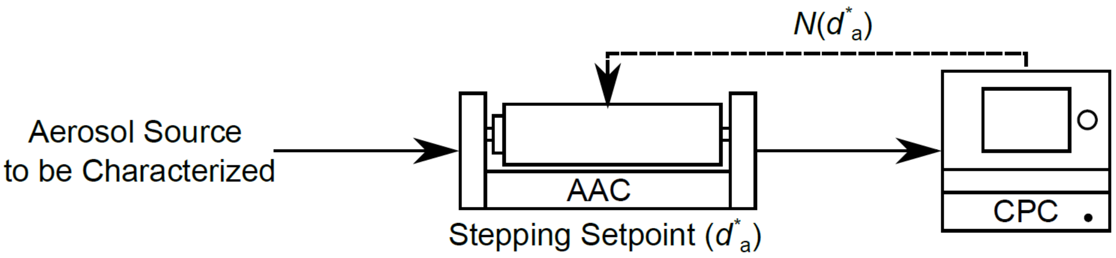
ω is varied over a scan, downstream CPC logged and inverted to give

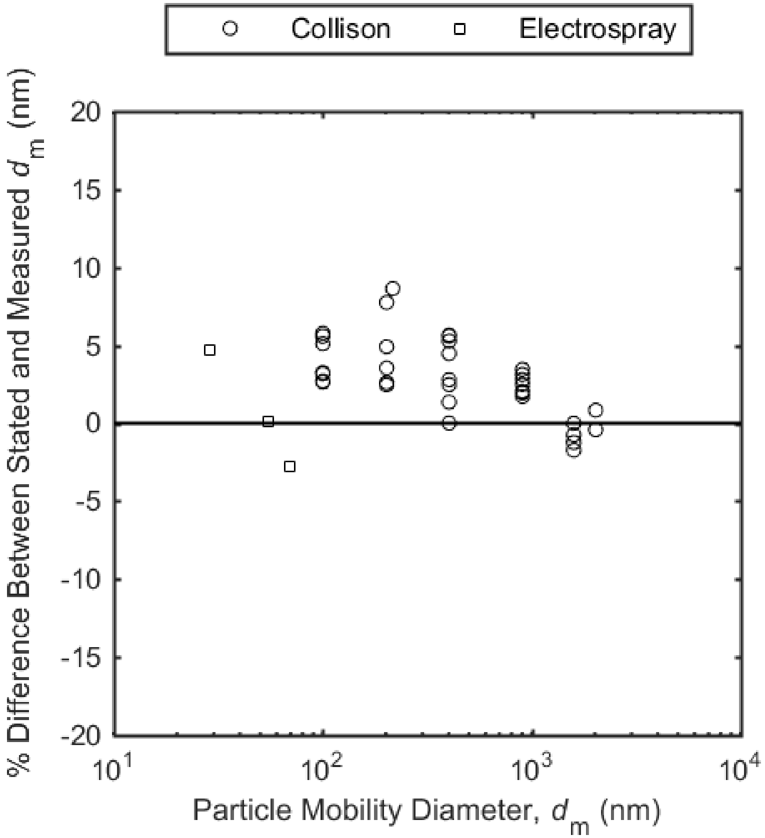
$$\frac{\mathrm{d}N}{\mathrm{dlog}d_{ae}} \text{ vs } d_{ae} \longrightarrow$$



*T.J. Johnson *et al.*, in preparation

Size Accuracy





Aerosol sources:

Duke Scientific & JSR Polystyrene Latex Spheres

Aerosolised with:

- TSI electrospray (<100 nm)
- BGI Collison nebulizer (>100 nm)

Classification Performance – Tandem AACs

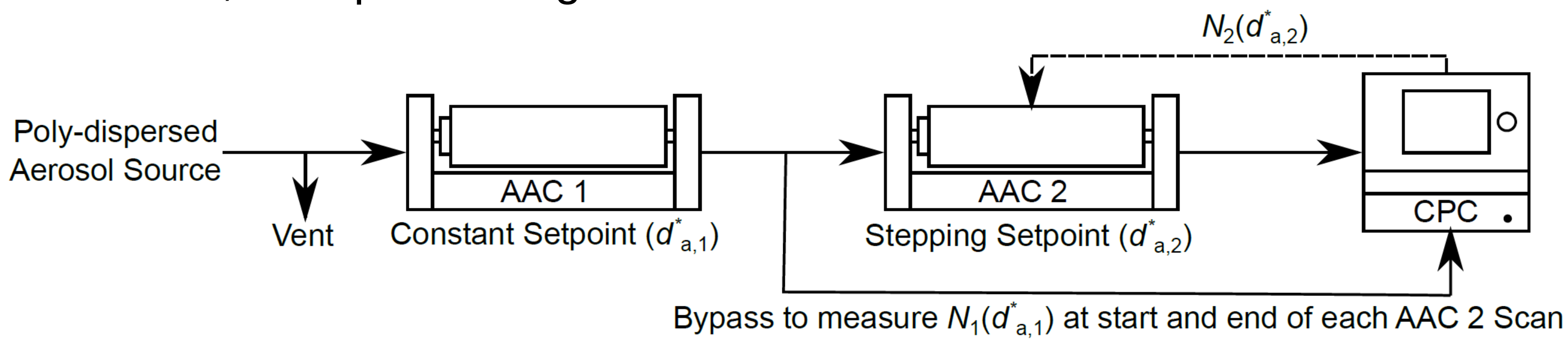
Transmission Efficiency (λ_Ω)

Scales area under transfer function
Ideal behaviour ⇒ 1.0
<1.0 ⇒ losses, >1.0 ⇒ gains

Transfer Function Width Factor (μ_Ω)

Scales FWHM
Ideal behaviour ⇒ 1.0
<1.0 ⇒ broader, >1.0 ⇒ narrower

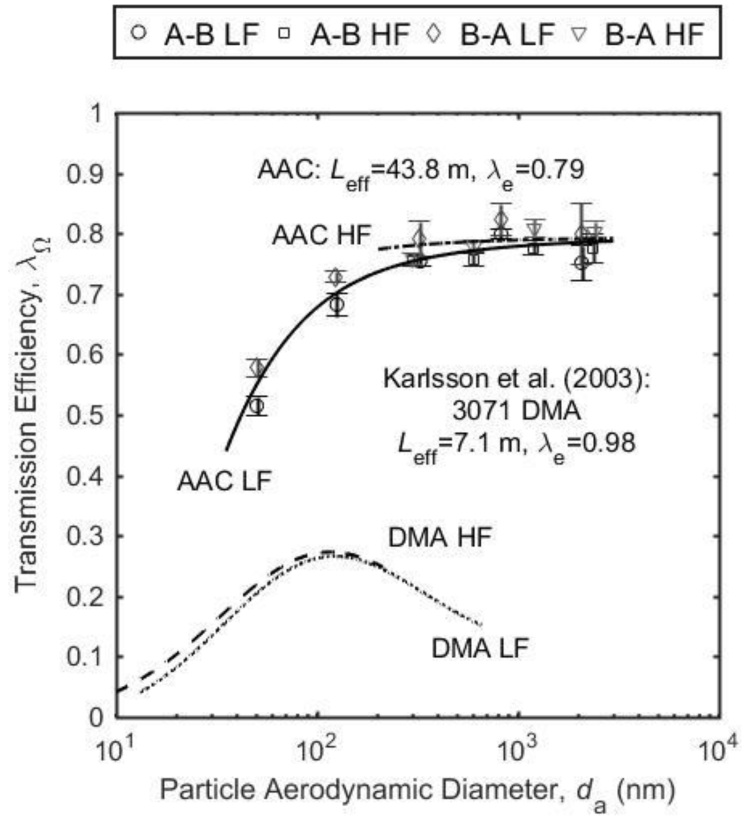
λ_Ω and μ_Ω determined by scanning the monodisperse output of one AAC with another AAC, then performing a deconvolution

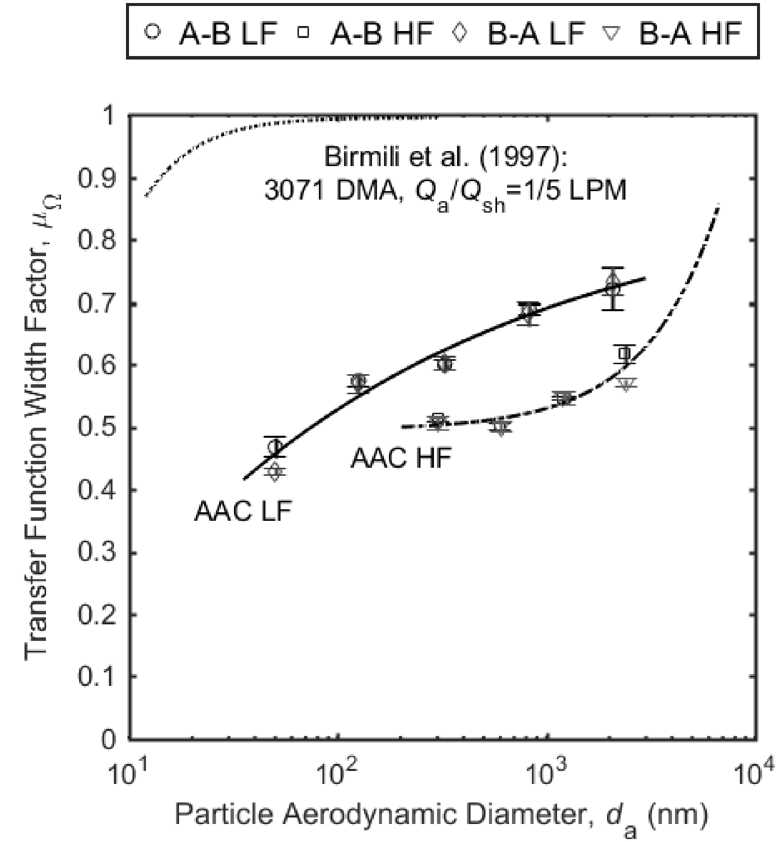


$$\frac{N_2(\tau_2^*)}{N_1} = \frac{\int \eta_i(d_{a,2})\cdot\Omega_{NI,1}(\tau_1,\tau_1^*,\beta_1,\lambda_{\Omega,1},\mu_{\Omega,1})\cdot\Omega_{NI,2}(\tau_2,\tau_2^*\cdot\tau_{agree}^*,\beta_2,\lambda_{\Omega,2},\mu_{\Omega,2})\cdot dN_i}{\int \eta_i(d_{a,1})\cdot\Omega_{NI,1}(\tau_1,\tau_1^*,\beta_1,\lambda_{\Omega,1},\mu_{\Omega,1})\cdot dN_i}$$

Transmission Efficiency & Broadening Results

Resolution (R) = 10: LF ("low" flow): $Q_a/Q_{sh} = 0.3/3$ LPM, HF (high flow): $Q_a/Q_{sh} = 1.5/15$ LPM





Maximum theoretical λ for AAC, away from diffusion regime, = 0.9

1. AAC reaches 0.8/0.9 = 89% of max transmission away from diffusion loss regime – small particle losses consistent with diffusional loss
2. AAC "losses" much lower than neutraliser + DMA system across all sizes
3. AAC transfer function approx twice as broad as expected – this probably due to imperfect flow distribution, especially as rotating

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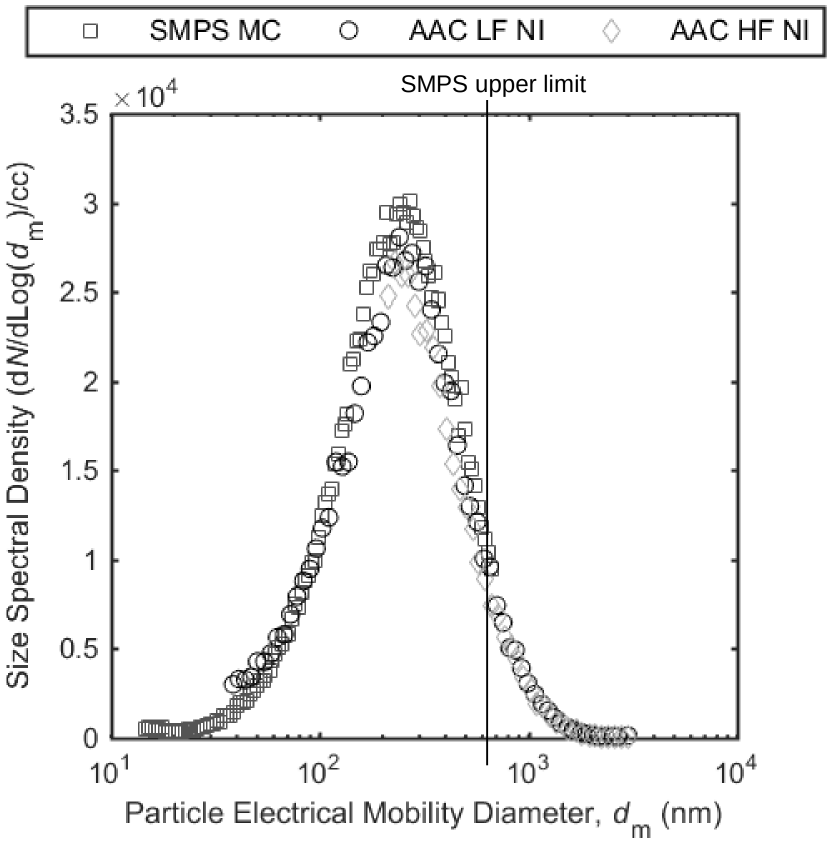
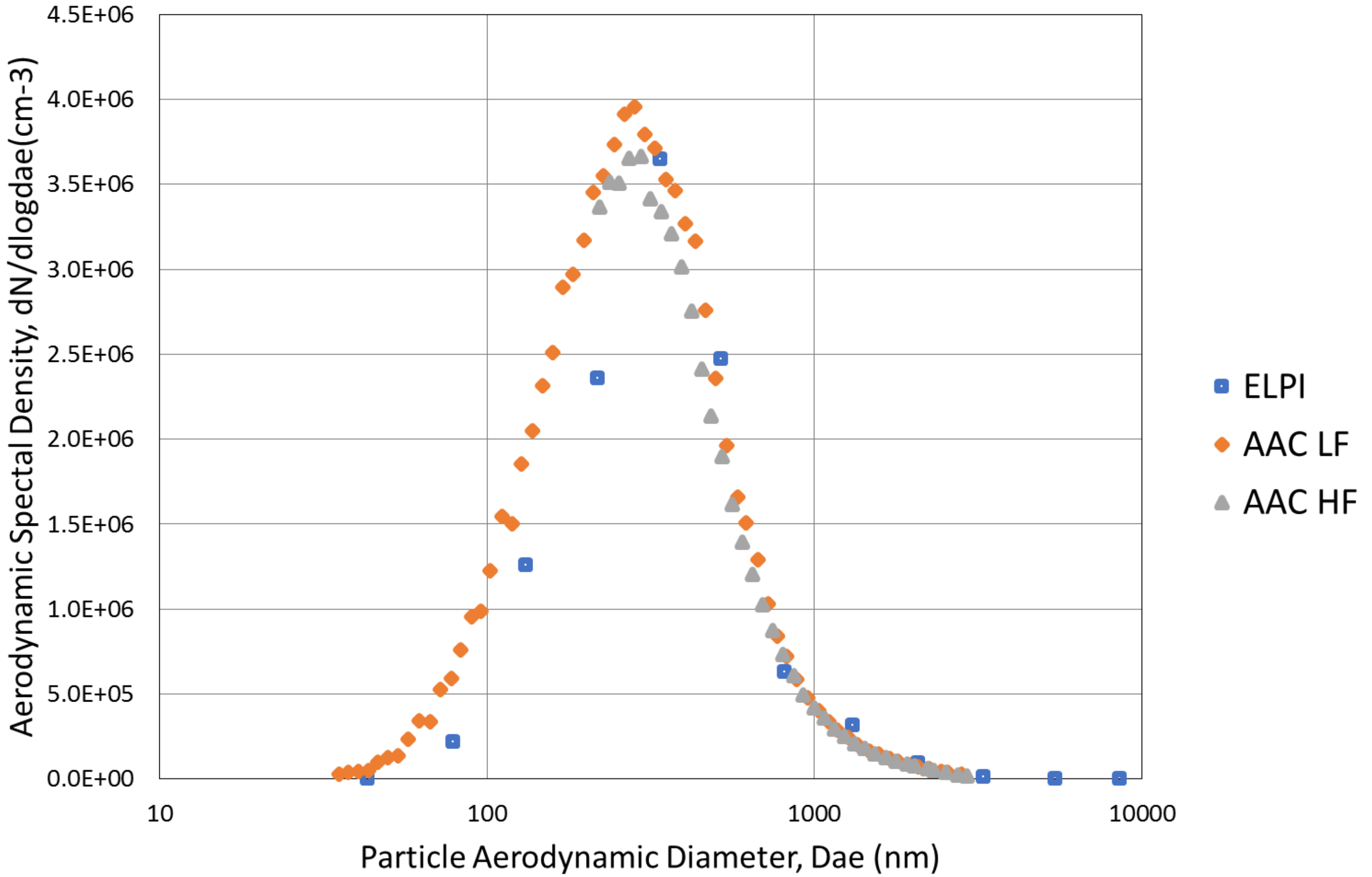
Step-scan comparison with SMPS



- DOS nebulized by constant output atomizer
- Both SMPS multiple-charge correction, and empirical AAC losses/broadening correction based on tandem experiments were used. AAC data converted to mobility metric.
- High degree of agreement between corrected AAC and SMPS/CPC measurements (*CMD*, *GSD* and N_{total} agreement of -0.8%, 1.2% and 1.4% respectively)

Step-scan comparison with ELPI

DOS nebulized by constant output atomizer



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Conclusions

- AAC provides a means to select a monodisperse aerosol without charging it – removing multiple charging effects, and mitigating particle loss due to charging efficiency.
- AAC provides a means to select a monodisperse aerosol by aerodynamic diameter
- Production instrument has a size range 25 nm – 5 μm+
- Production instrument accuracy and transmission efficiency excellent
- Production instrument broadening more than expected – but still comparable resolution to a DMA
- Can currently be stepped scan to yield a size spectrum

References

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- Wiedensohler, A. (1988) *An approximation of the bipolar charge distribution for particles in the submicron size range*, Journal of Aerosol Science, **19**, 387–389

Any questions?

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Booth #13 at AAC

www.cambustion.com/aac