Bleed Air Contaminant Particulate Measurements

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Bleed Air Contaminant Particulate Measurements

• Bleed air simulator measurement
  – Phase 1
  – Phase 2
• VIPR program
• Test stand turbine engine measurements
BAS – Phase 1

- Particle size distribution from the simulator for the following conditions:

<table>
<thead>
<tr>
<th>Point #</th>
<th>Base</th>
<th>Temp, °C (°F)</th>
<th>Press, kPa (psi)</th>
<th>Temp, °C (°F)</th>
<th>Press, kPa (psi)</th>
<th>Temp, °C (°F)</th>
<th>Press, kPa (psi)</th>
<th>Temp, °C (°F)</th>
<th>Press, kPa (psi)</th>
<th>Temp, °C (°F)</th>
<th>Press, kPa (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No Heat</td>
<td>200 (29)</td>
<td>100 (212)</td>
<td>200 (29)</td>
<td>230 (445)</td>
<td>690 (100)</td>
<td>230 (445)</td>
<td>200 (29)</td>
<td>280 (535)</td>
<td>200 (29)</td>
<td>280 (535)</td>
</tr>
<tr>
<td>2</td>
<td>185 (365)</td>
<td>200 (29)</td>
<td>200 (392)</td>
<td>200 (29)</td>
<td>250 (490)</td>
<td>690 (100)</td>
<td>—</td>
<td>—</td>
<td>280 (535)</td>
<td>340 (50)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>230 (445)</td>
<td>460 (67)</td>
<td>240 (464)</td>
<td>200 (29)</td>
<td>280 (535)</td>
<td>690 (100)</td>
<td>230 (445)</td>
<td>480 (70)</td>
<td>280 (535)</td>
<td>480 (70)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>250 (490)</td>
<td>690 (100)</td>
<td>275 (527)</td>
<td>200 (29)</td>
<td>310 (590)</td>
<td>690 (100)</td>
<td>230 (445)</td>
<td>690 (100)</td>
<td>280 (535)</td>
<td>690 (100)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>280 (535)</td>
<td>480 (70)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>310 (590)</td>
<td>690 (100)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Particle Measuring

Aerodynamic Particle Sizer

• TSI Model 3321
• Measures aerodynamic diameter by recording the time of flight of particles as they are accelerated through a nozzle.
• Particle size is binned into 52 channels from 0.5µm to 20 µm.

Condensation Particle Counter

• TSI Model 3781
• Measures particle concentration by optical counting.
• Water is deposited by condensation onto the particles to make them large enough to be detected optically.
• Particles as small as 6 nm are counted. There is no binning.
Particle Measuring

Optical Particle Counter

- Climet Spectro 0.3
- Calculates particle size and concentration by measuring the intensity of light scattered by the particles.
- Particle size is binned into 16 channels from 0.3µm to 10µm.

Scanning Mobility Particle Sizer

- TSI 3496
- Uses ionization with electric field to separate particles by mobility
- Uses a CPC to count different size bands
- Size range from 10nm to 532nm.
Results

Size distributions from base study
Results

![Graph showing concentration vs. diameter for two temperatures: 185°C and 230°C. The graph has a logarithmic scale for both concentration and diameter.]
BAS – Phase 2

• Particle Sizing
• FTIR analysis of gaseous contaminants
• Collection of contaminant samples with absorbent tubes
Particle Measuring

Aerodynamic Particle Sizer

- TSI Model 3321
- Measures aerodynamic diameter by recording the time of flight of particles as they are accelerated through a nozzle.
- Particle size is binned into 52 channels from $0.5\mu m$ to $20\mu m$.

Scanning Mobility Particle Sizer

- TSI 3496
- Uses ionization with electric field to separate particles by mobility
- Uses a CPC to count different size bands
- Size range from 10nm to 532nm.
# BAS Experimental Conditions

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Pressure (psia)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td>185</td>
<td></td>
</tr>
<tr>
<td>220</td>
<td></td>
</tr>
<tr>
<td>250</td>
<td></td>
</tr>
<tr>
<td>280</td>
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<tr>
<td>310</td>
<td></td>
</tr>
</tbody>
</table>
SMPS 30 psia

Concentration (Number)

Diameter Midpoint (nano meters)

- 185 C - 30 psia
- 220 C - 30 psia
- 250 C - 30 psia
- 280 C - 30 psia
- 310 C - 30 psia
APS 100 psia

![Graph showing concentration (number) against aerodynamic diameter with micro meters on the x-axis and concentration on the y-axis. The graph includes lines for different pressures: 185 C-100 Psia, 220 C-100 Psia, 250 C-100 Psia, 280 C-100 Psia, and 310 C-100 Psia.]
Conclusions from BAS Measurements

• Bulk of particle counts below 300 nm
• Higher temperatures generate substantially more ultrafine particles, likely smoke generation
• Generation of increased ultrafine particles at elevated temperatures not likely tied to apparatus
Bleed air contamination detector?

Ionization smoke detectors work well for $d < 300 \text{ nm}$
Vehicle Integrated Propulsion Research (VIPR)

• Multi-year, multi phase NASA program
• Other players include Air Force, Boeing, Pratt and Whitney, MAKEL, and the FAA
• Many objectives but overall focus is real time engine health monitoring
• Bleed air contaminant measurements a small, but important, piece of the program
VIPR Test Bed

Boeing C-17 Globemaster III
VIPR Experimental Apparatus

Bleed Air System Test Rig
VIPR Bleed Air Data
VIPR Plans

• Anticipate next phase of measurements in early 2015
• ACER Participation???
Test Stand Turbine Engine

• BAS simulator can reproduce pressure and temperature but not the same environment
• Turbine engine compressor is nearly adiabatic with vanes and high speed blades. All heating is due to compression.
• BAS uses non-adiabatic reciprocating piston compressor with after-heater.
Test Stand Turbine Engine

• Are particle characteristics universal or specific to the bleed air apparatus?
• Are particle characteristics dependent upon the nature of the aerosol introduction?
• Real aircraft engines (e.g. VIPR) are the ultimate answer but very expensive and difficult to run experiments.
• Small engine can answer most questions at fraction of the cost.
Allison T63
Measurement Equipment
Lots of work to do before August