ACCORD Inlet Committee Report

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The committee was charged with assessing the currently available inlets for NSF aircraft, identifying gaps and present sampling problems, and developing possible solutions to address shortcomings.

The panel discussed both gas-phase and particle sampling issues. This is a report of general findings of the inlet committee and current recommendations for possible research and development projects:

1. **Aircraft flow fields, boundary layer thickness**

A fundamental basis for interference-free sampling is the knowledge of the flow fields and boundary layer thickness around the aircraft skin as well as possible ingestion of cabin air from areas prone to leaks (such as doors) and vents (such as main cabin vents and heat exchangers).

It is not clear at this time how well we really understand the flow fields around the NSF aircraft. This includes not only the boundary layer thickness and how this changes with aircraft attitude, but also influence of cabin vents. Test flights have been conducted to determine boundary layer thickness around both NSF aircraft. During TOPSE, there were indications that some of the right side forward cabin inlets could be influenced by the main cabin vent. Further tests have not been conducted however, but should be done at some point in time. Perhaps comparing a CO2 measurement on both sides of the aircraft could help settle this issue.

It would also be desirable to conduct a full CFD simulation of the GV aircraft and compare it with results from the tests done by Teresa Campos and others with the pressure rake inlet in flight.
The same tests would be helpful for the C-130 as well to determine the best locations for inlets for aerosols and reactive gases. Up to now these locations have mostly been chosen by best guess, and forward on the aircraft.

Action items:

- Chuck Wilson's spring CFD class could help out (work on the GV model as a class project) but there may be issues with the GV exterior model still being proprietary information.
- Mark Lord will look into obtaining the model, Teresa will provide the data collected with the pressure rake inlets.

2. Reactive gas phase measurements

While the current GV reactive gas inlet (originally designed for DC3) has proven sufficient for many reactive gases (VOC, CH_2O, peroxides), problems still exist with very sticky compounds (such as HNO_3 and NH_3, organic acids). In particular, the sampling of large gradients (such as through the PBL or in fresh pollution plumes) can be complicated by slow equilibration of inlet surfaces with the ambient sample, causing delayed instrument response and/or a hysteresis effect.
These issues could potentially be solved by using inert surfaces (such as PFA or glass) and employing turbulent inlet flow. This maximizes wall contact and may significantly accelerate equilibration between the inlet walls and the ambient air.

Action item:

- Tests should be conducted validating this approach, possibly during one of the ARISTO deployments over Colorado. A fast NH_3 and HNO_3 instrument would work well for this.

The reactive gas inlets currently available on the NSF aircraft do not work well for gas phase measurements of radicals and other ultra-reactive species, which often are irreversibly removed or transformed by reaction on inlet walls (such as halogens and halogen oxides). The exception to this is the proven HO_x inlet (located at CU Boulder), which is designed to fly on the C-130 or other turboprop aircraft.
A similar inlet could be flown on the GV, but currently can only be mounted to one of the belly aperture plates. A preliminary design exists for a HO_x instrument placed directly above this aperture, but this design was never completed. It should be explored whether a CIMS instrument for halogen measurements could be deployed in the belly of the GV. Alternatively, the approach used by DLR (top of fuselage, close to front of aircraft) could be investigated as an option. Another alternative path could be the deployment of a Low-Turbulence Inlet (LTI) systems for the measurement of highly reactive gases since wall losses should be minimized. This could work for ultra-reactive gases like halogens and halogen oxides, but likely not for HO_x radicals. Issues with LTI use on the NSF aircraft are discussed below in the particle measurement section. For all of the alternatives above, connecting tubing length from the inlet to the instrument can still pose challenges, however.

A good alternative to a location at the fuselage would be to install ultra-reactive gas measurement instrumentation into a GV wing pod. The inlet could be placed at the front of the pod lined up with the sampling axis of the instrument, thus eliminating common inlet issues for cabin deployment. If successful, the GV pod could also be adapted to the C-130, making deployment of pod mounted instruments much easier. The pod solution was identified by the panel as the preferred alternative. (This option has been explored in ACOM and EOL, but was not put forward as a MRI proposal because of the prohibitive cost sharing requirements).

Action items:

- Actively explore installation of ultra-reactive gas-phase instrumentation into GV pod. Start with GaTech CIMS for halogen measurements. Adapt GV pod to C-130.
- Explore the use of LTI inlets for highly reactive gases.

Low Turbulence Inlet (LTI)

The LTI that is currently being deployed on board the NOAA P-3B aircraft is operated off a 12" diameter "doughnut" venturi (approx. 4" depth) that is mounted under the belly of the aircraft, similar in design to that used on the NASA DC-8. However, on the P3B it only allows for about 70% of the volume flow rate required for optimal operation of the LTI.

The C-130 LTI is functional but currently mothballed. The main reason is the excessive noise and heat output as well as power consumption of the bypass pump. Venturi systems available for the C-130 were not sufficient to generate the required inlet flow rate.

The NCAR/NSF Electra had an engine-driven venturi pump capable of generating flow rates in excess of 1000 liters/minute. (At an altitude of 6,500 ft, this source provided flow ranges from 45 SCFM at a pressure drop of 60 mM Hg to 0 SCFM at a pressure drop of 530 mM Hg.) The NASA Electra also had an engine-driven venturi capable of similar flow rates. As it would be beneficial for accurate sampling of large particles as well as highly reactive gases the panel recommends that EOL examine the possibility to retrofit an engine-driven venturi pump to the C-130, and possibly also the GV. In case of the GV it is unlikely that a large venturi shroud can be flown because of unacceptable aerodynamic drag.
For the C-130, another option would be to start with the current venturi used on the NASA DC-8 and optimize it to deliver a sufficient flow rate at C-130 speeds. True isokinetic operation would minimize corrections that have to be made to the measured parameters. Chuck Wilson might be able to have one of his spring classes do CFD modeling to develop a venturi for the C-130, possibly based on the current

design for the DC-8. If optimal flow rates can be achieved, particles up to ~12 micron should be possible through the LTI (as was shown on the BAE-146 during the FENNEC campaign in 2011; previous tests on the DC-8 during PELTI and DICE showed good sampling of particles up to 7 microns)

Action items:

- Once the LTI for the C-130 is available, tests should be performed to validate the utility of the LTI for the measurement of extremely reactive gases such as bromine oxides, hydrobromic acid, and halogen oxides, and compare the performance, for example to the current GV chemistry inlet.
- Tests should also be conducted to determine whether a shrouded design helps eliminate artifacts related to LTI tip design.
- The panel recommends that a "venturi shroud library" be compiled and posted on the ACCORD web site so that investigators needing to use a venturi (for any purpose) can easily find out what is available for which aircraft and how to request it.

Interstitial particulates in clouds

The panel discussed inlet issues regarding sampling of interstitial aerosols in clouds. Several designs have been compared for sampling in clouds. Suresh Dhaniyala's group evaluated the performance of SMAI (forward facing cone), SDI (diffuser) and BASE (blunt body) inlets. Under almost all conditions, SMAI and BASE performed better than conventional forward-facing inlets (such as SDI). The shatter artifacts in SMAI and BASE were either absent or present in very low numbers when the cloud droplets were not very large (i.e. cloud droplet diameters < 50 μm). When the cloud droplet diameters increased in size or if drizzle was present, the shatter artifacts in the inlets became significant. The inlets seemed to perform well (i.e. minimal or no shatter artifacts) in the presence of ice.

During ICE-T, Suresh's group measured size distributions of interstitial aerosol downstream of SMAI and BASE (after the sampled aerosol was dried) using a fast SMPS system. When shatter artifacts were present, particles smaller than 40 nm were seen to be enhanced in number. Thus, with SMAI and BASE, even in the presence of shatter artifacts, interstitial aerosol characteristics can be obtained reasonably accurately for particles larger than 50 nm.

One possible approach to identify sample periods when interstitial aerosol are sampled without shatter artifacts, is to measure CN counts using both BASE and SMAI inlets and if the CN counts are very similar with aerosol sampled from two inlets of very different designs, then it can be assured that the sample is shatter-artifact free.

Action items:

- none

Particle rejection for gas phase measurements

Unwanted sampling of particulates can cause interference in some gas phase measurements, particularly NO_y and NH_3.
While the sampling of larger particles can be limited by taking advantage of their inertia, it is difficult to reject small particles as they behave increasingly like gas molecules with decreasing mass and size. Standard, side-facing inlets will ingest particles up to 0.5 micron in size, depending on aircraft speed and attitude.
For the ATOM experiment, NOAA has developed an inlet for NO_y that should reject particles over 100 nm in size, at DC-8 speeds. However, at P3 or C-130 speeds, this cutoff would be significantly larger, so additional research is required for slower aircraft. Chuck Wilson's CFD class could conduct modeling on such an inlet design and see about making the design more efficient for slower aircraft.

Action item:

- After completion of ATOM, the particle rejection efficiency may be characterized for the DC-8 application. The panel recommends using the results from ATOM to conduct CFD modeling followed by developing, building, and testing an inlet design for deployment on turboprop aircraft.