Air Sample Inlets for HIAPER
- Development Plan -

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1. INTRODUCTION

The new HIAPER aircraft will carry a wide assortment of gas and aerosol sampling instruments. The overall quality of gas and particle measurements will depend significantly on the performance of the air sampling systems (inlets and piping). During the initial testing and research flights, the instruments will be rack-mounted inside the aircraft cabin and will need inlets and piping to bring outside air to the rack locations. ATD is tasked with the design, fabrication, approval, and testing of inlets that are suitable for airborne research. This document outlines the development plan of inlets for basic gas and particle measurements in the STANDARD and ROUTINE categories, as defined by the "*HIAPER Instrumentation Priorities*" report (HAC, 2003). These inlets will be available for use during *Progressive Science* missions that are expected to start approximately mid-June 2005. Ultimately, there will be a variety of other inlets for the aircraft. Some of these will be developed within ATD, others may be provided through the *NSF HIAPER Instrumentation Solicitation*, and some may be from scientific investigators.

This document describes the proposed development process. It identifies the scientific, engineering, and safety issues and outlines the schedule and staffing resources needed. Information was gathered from the *GV Investigator's Handbook (version March 2004),* summaries by the HIAPER *Integration Product Team* (IPT) subgroups, the *Airflow Analysis* survey report prepared by ATD (*http://raf.atd.ucar.edu/Airflow/*), the HAC's *Instrumentation Priorities* report, and relevant scientific workshops and literature.

2. PERFORMANCE GOALS & DESIGN ISSUES

The air sampling systems described here are not just the inlets. The overall performance depends on everything from inlet to exhaust, and so this development plan attempts to address the entire system except for the instruments themselves. The plan includes: inlets, piping sufficient to bring the samples inside the cabin (within reach of racks), sensors in sample lines to measure temperature, pressure and humidity, more piping to join the "chemical" exhaust piping. If a need is identified, the design plan may address suction requirements, for example from pump(s) or scarf tube(s). The temperature-pressure-humidity sensors will probably be downstream so as to avoid interference with the gas or particle species of interest. A conceptual drawing showing the layout of these components is shown in Fig. 1.

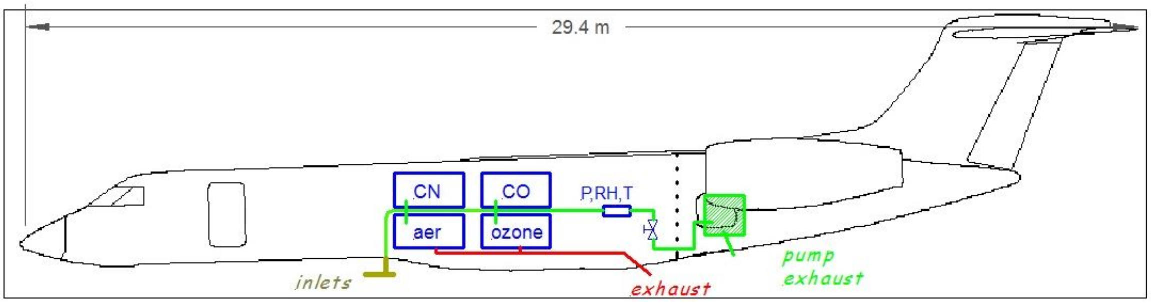


Fig. 1. Conceptual layout of basic inlet & exhaust system.

Two kinds of inlets will be designed, built, installed, and tested:

- *trace gas inlet* will target ozone and carbon monoxide
- *two versions of a small aerosol inlet*: one forward-facing and one aft-facing. Target particles are 5 nm to 2 µm diameter

These inlets will be mounted on the GV fuselage and provide air samples for rack-mounted instruments in the cabin. The inlets may share an aperture pad, or they may be mounted on separate pads or hard points. Since these inlets are likely to be on the aircraft for all research flights, a study of optimal locations will be part of this development plan. Possible mounting locations are shown on the following two figures from the *GV Investigator's Handbook.*

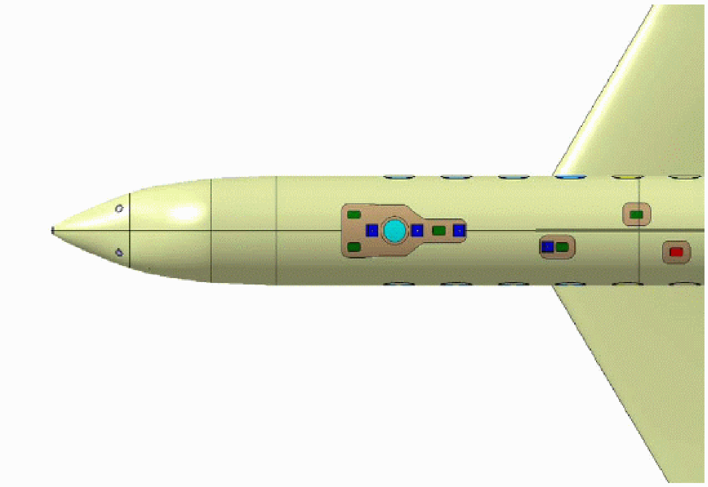


Figure 2.2. View of GV upper fuselage, showing inlet aperture pads (green and red), optical view port (light blue), fuselage mounts (dark blue), and two (2) forward fuselage pads below windscreen (grey circles). *Drawing courtesy of Lockheed Martin.*

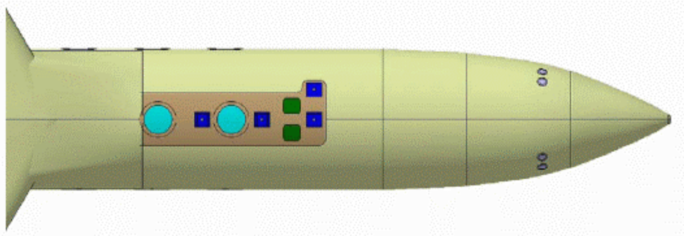


Figure 2.3. View of GV lower fuselage, showing instrument aperture plates (green), optical view ports (light blue), fuselage mounts (dark blue),and four (4) forward fuselage pads (grey circles). *Drawing courtesy of Lockheed Martin.*

Inlet designs will be driven by the performance requirements, sampling efficiency, and operational safety. There is no such thing as an inlet that can serve all instruments for sampling all gas or particle species. Nevertheless, a variety of issues will be considered. Factors that apply to specialty applications are beyond the scope of this endeavor (e.g., counter-flow, low-turbulence, total air aerosol sampler, dichotomous sampling, whole air gas sampling, etc.). Design goals common to trace gas and aerosol inlets include:

- acceptable in-flight icing risk
- shortest distance from inlet tip to instrument
- chemically inert interior
- sample from free stream, outside the aircraft flow boundary layer (scales to ~1% of distance from nose)
- minimize obstruction or interference with other sensors
- minimize obstruction and hazard to crew working near inlets & piping
- avoid compression heating of sample
- minimize aerodynamic drag

The design will use 227.5 m s^{-1} (442 KTAS) to represent the typical research true air speed, as described in the GV Investigator's Handbook and reproduced here:

> For preliminary planning purposes, a research speed for NSF/NCAR GV of 240 KCAS up to 40,000 feet and Mach number 0.77 above 40,000 feet should be considered. The true airspeed (KTAS) and Mach number for these speeds are shown in the table below.

Altitude, feet	KCAS	KTAS	Mach No.
0	240	240	0.36
10,000	240	277	0.43
20,000	240	323	0.52
30,000	240	379	0.63
40,000	232	442	0.77
45,000	206	442	0.77
50,000	184	442	0.77

Table 3.2. GV calibrated airspeed, true airspeed, and mach number versus altitude.

2.1 *Aerosol Inlet System Specifications*

The basic aerosol inlet will provide a single source of air that can be divided among several instruments in the cabin. The performance specifications are listed in the following table. Manual flow control will be used to adjust the flow to achieve isokinetic sampling at the inlet tip for the research reference speed, 227.5 m s^{-1}. We expect that subsequent inlet systems will have additional features such as: automatic flow regulation, tip heating to avoid ice build-up in super-cooled water clouds, and monitoring of tip temperature.

Feature	Specification	Comment
Flow at tip	iso-axis……. free stream… isokinetic…	aligned with airflow outside aircraft boundary layer air speed 227.5 m s^{-1}
Total system flow	monitor … regulate….	volume flow rate, temperature, pressure, RH manual adjustment
Particle size range	5 nm to 2 µm passing efficiency > 80%	diameter, dry size
Diffuser-Decelerator		decelerate flow; stop distance of 5 µm particle < 5 mm* at pick-off point
Chemical reactivity	inert	tip & interior
Electrical resistance	conductive	
Mounting location	belly	standard aperture pads; avoid upstream contamination & flow distortion

*assume particle mass density 2 g cm^{-3}

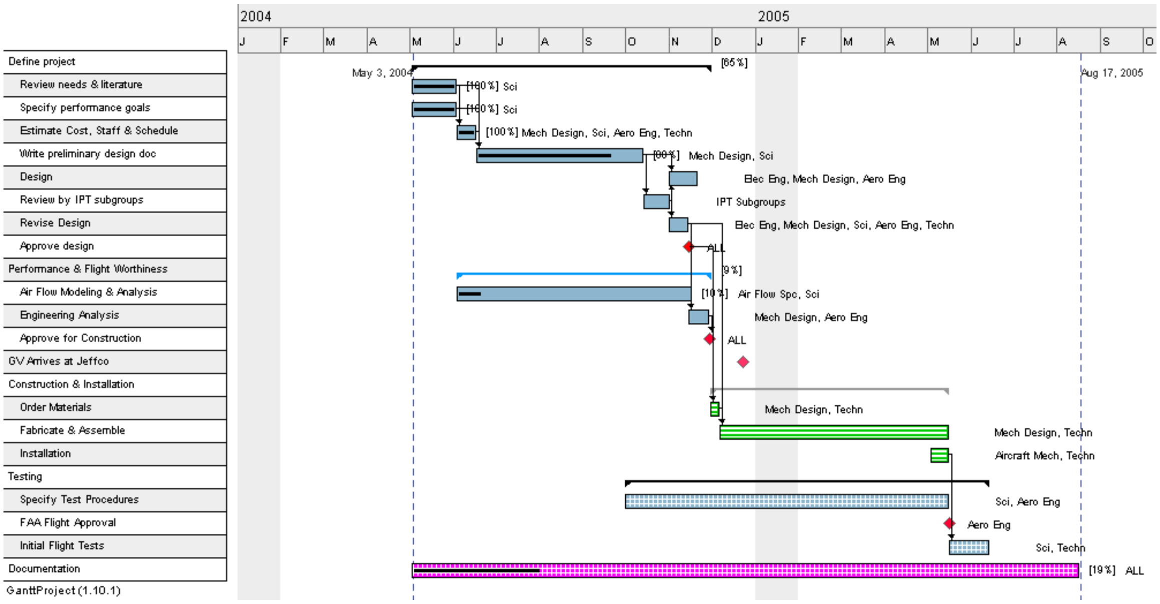
2.2 *Trace Gas Inlet System Specifications*

The basic trace gas inlet will provide a single source of air that could be divided among several instruments in the cabin. Performance specifications are listed in the following table. Note that the inside of the inlet's strut should be large enough to accommodate heating of the sample tube, a separate tube taking calibration gas near the tip, and a 3-way valve to select the source (sample or calibration).

Feature	Specification	Comment
Flow at tip	iso-axis……. free stream…	aligned with airflow outside aircraft boundary layer
Total system flow rate	1-10 SLM range	
	regulation	electronic rate control
Mounting	locations	upper and lower fuselage on standard aperture pads, hard points, and optical ports
	orientation	aft facing
Physical design goals	aft facing	inhibit large particle entrainment
	materials	stainless exterior; option to catheterize with inert tubing
	inhibit liquid water entrainment	outer stainless body designed with tip shaped to deflect liquid water with minimal aerodynamic drag; lip on outside of strut to shed streaming water
	anti-icing	single design includes capability for anti-icing implementation to proactively meet all potential mounting location needs
Assessment	downstream characterization	monitor mass flow rate, temperature, pressure, RH
	upstream flow distortion	include valving to sequentially sample ozone from upper and lower fuselage locations to assess whether acceleration of air passing over fuselage creates an artifact in the chemical field
	downstream flow distortion potential	sequentially sample at aftward aperture locations to assess potential for downstream mixing of boundary layer air with free stream air

3. TASKS, STAFF, SCHEDULING & FUNDING

Scheduling of tasks is shown in Figure 4. Milestones are indicated for design approval, construction approval, approval for flight testing, and project completion. The target finish date is mid-August 2005.



The design task will be shared by a combination of ATD engineering and scientific staff. Engineers and scientists will collaborate on the selection of materials. Airflow modeling will be done in support of the design. It will provide guidance for aligning the inlets, estimating drag forces, and estimating particle passing efficiency. Aeronautical engineering and maintenance staff are responsible for evaluating flight worthiness and obtaining FAA approvals. ATD/Design and Fabrication Services (DFS) has major responsibility for design and construction. RAF mechanical and technical support staff will handle the installation. Tests will be specified to help assess inlet performance.

Table 1. Tasks and key personnel.

task	*responsible person*	*target completion dates*
write performance specs	Dave, Teresa	30-June-2004
airflow modeling study	Dave (Cindy review)	16-Nov-2004
select possible mounting locations	Dave, Teresa, Mark	14-Oct-2004
material selection	Dave, Teresa, Mark, Jack	7-Nov-2004
design	Jack, Mark, EE	Nov 2, 2004
design approval	ALL	30-Nov-2004
construction	Jack	21-May-2004
installation	Kurt, Mark	18-May-2005
approve for flight testing	Mark	18-May-2005
testing & analysis	ALL	18-Aug-2005
acceptance	ALL	18-Aug-2005
documentation	ALL	18-Aug-2005

4. REVIEWS & APPROVAL

The inlet designs will be submitted to the following four IPT subgroups for review: *Safety & Certification, Chemistry Instrumentation, Aerosol & Microphysical Instrumentation*, *Inlets & Airflow Analysis*. Comments and recommendations from these groups will be analyzed and may result in modifications to the preliminary design. After revision, the final design will be approved by ATD engineering and scientific staff, and construction will then start. Before flight tests can begin, the design and engineering data must be reviewed and approved by the FAA.

5. DOCUMENTATION

Documentation will be prepared to describe the performance goals and design process, materials and methods of construction, mechanical drawings, photos, engineering calculations, materials list, airflow study results, testing, and a performance summary. Sections from the documentation will be suitable for including in the *GV Investigator's Handbook.*

6. INFORMATION RESOURCES

HAC, 2003 - Coffey, M., E. Condon, A. Cooper, J. Francis, C. Friehe, C. Gardner, D. Jorgensen, D. Lenschow, R. Rogers, L. Russell, E. Saltzman, R. Smith and G. Vali: *HIAPER Instrumentation Priorities, a Report to the NSF from the HIAPER Advisory Committee,* 13pp.

Wendisch, M., H. Coe, D. Baumgardner, J.-L. Brenguier, V. Dreiling, M. Fiebig, P. Formenti, M. Hermann, M. Krämer, Z. Levin, R. Maser, E. Mathieu, P. Nacass, K. Noone, S. Osborne, J. Schneider, L. Schütz, A. Schwarzenböck, F. Stratmann, and J. C. Wilson, 2004: Aircraft Particle Inlets: State-of-the-Art and Future Needs, *Bull. Amer. Meteor. Soc.*, **85**, 89–91, and *Electronic Supplement,* 8pp.

Wilson, J. C., and W. R. Seebaugh, 2001: Measurement of Aerosol from Aircraft. Aerosol Measurement, 2d ed. P. Baron and K. Willeke, Eds., John Wiley & Sons, 887–901.

[+ many more references. Need to add citations in text of this plan]